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THE UNIVERSITY OF ALBERTA

INTERMOLAR WIDTH CHANGES ASSOCIATED WITH
BORDER MOVEMENTS AND THEIR RELATION TO AGE

BY

STEVEN KELLY DAVIS



A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
MASTER OF SCIENCE
IN
CLINICAL SCIENCES
(ORTHODONTICS)

FACULTY OF DENTISTRY

EDMONTON, ALBERTA

SPRING 1991



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and their relation to age
Master of science in clinical sciences

1991

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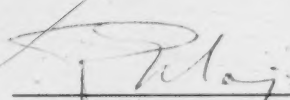
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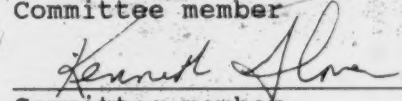
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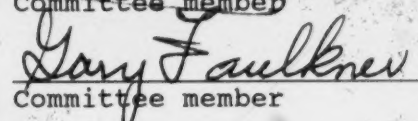
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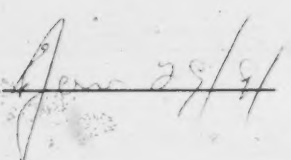

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ABSTRACT

A transducer utilizing bonded metallic strain gauges was designed and fabricated to measure intermolar width changes when the mandible underwent wide open, protrusive, and lateral movements. Fifty-eight subjects were divided into two age groups, twenty-seven 13-15 year olds and thirty-one 21-28 year olds. Participants had minimal tooth mobilities (periodontal index 1 or less), Class I molar relationships, and no overt symptoms of temporomandibular joint dysfunction. Each subject was instructed to move their mandible into border positions and intermolar width change was measured. A coil spring device was also utilized, with the subject's jaw muscles relaxed, to determine the amount of intermolar width change that occurred with assisted opening. While undergoing wide open border movements, a Kinesiograph was used to measure mandibular position. The means for maximum intermolar width change that occurred with voluntary wide open border movements were, $-.285$ mm for both age groups, followed by protrusive border movements ($-.259$ mm for adolescents and $-.167$ mm for adults), forced open (assisted) movements ($-.140$ mm for adolescents and $-.125$ mm for adults), left lateral movements ($-.112$ mm for adults and $-.097$ mm for adolescents), and right lateral border movements ($-.092$ mm for adults and $-.091$ mm for adolescents). It was concluded that intermolar width changes associated with jaw movement were statistically significant and clinically relevant.

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Chapter 1

INTRODUCTION

The mandible has a unique shape and means of articulation in the human skeleton. When viewed from above, the mandible is horse-shoe shaped with the open ends of the horseshoe terminating at the temporomandibular joints, which are capable of hinge and sliding movements in three planes of space¹. The mandible is generally considered to be a rigid structure, but, in fact, is not. If sufficient force is applied, at the correct location and in the right direction, the mandible can undergo shape changes.

The actions of the muscles of mastication, and to a lesser extent, the suprahyoid and infrahyoid muscles, apply torquing stress on the mandible which may result in distortion, although the synergetic action of the muscles minimizes any potential for shape change. For example, the masseter muscle exerts a lateral force vector which may be offset by the medial pterygoid muscle. The only muscles acting on the mandible without an apparent force compensation are the lateral pterygoids.² The lateral pterygoid muscle originates on the lateral surface of the lateral pterygoid plates and on the greater wings of the sphenoid bone and passes in a posterior-lateral direction to insert into the anterior surface of the condyle neck and the articular disk.¹ Contraction of the lateral pterygoid muscles, therefore, will not only pull the mandible forward, but will also pull the

condyles medially potentially causing an adduction of the mandible (Figure 1).



Medial Force Vectors Produced
by Lateral Pterygoid Muscles

Fig. 1

The thick cortical plate along the lower anterior border and the bony reinforced mental protuberance has developed to partially compensate for the mandible's tendency to bend².

a. Statement of the Problem

The distortion of the mandible caused by contraction of the lateral pterygoid muscles has been compared to an archer's bow; with the mandible being the bow and the lateral pterygoid muscles, the string.³ Varying degrees of mandibular flexure have been noted at the transverse dental plane when the mandible was subjected to a variety of forces^{2,3,16-21,24-27}.

The amount of flexure is sufficient to be taken into consideration by the dentist for the following reasons:

1) The mandible may be distorted while taking impressions. A prosthesis fabricated to fit on the inaccurate model may not seat.

2) Extreme accuracy is needed in modern dental rehabilitation. Interocclusal records have to be very accurately recorded in orthodontic treatment as well as other dental disciplines to determine condylar position. Techniques to determine condylar position such as MPI readings used in the SAM 2^(a) articulator system may be erroneous if there is distortion of the dental models.

3) Mandibular flexure during mandibular movements may cause undue stress on abutment teeth onto which fixed or removable prosthesis are attached. The stresses incurred would appear to be even more significant with dental implants which do not have any periodontal ligament compensations.

4) The fit of orthodontic appliances such as retainers and positioners could be affected. Wearing an orthodontic positioner constructed to a distorted mandibular model might distort the dental arch and an inaccurate acrylic mandibular retainer may cause discomfort.

5) Mandibular dentures may be also be ill-fitting because of distorted models. Wear of lower dentures as well as

^a SAM Prazisionstechnik, Taxisstrasse 43, D-8000, Muchen Germany. Distributed in North America by Great Lakes Products, Buffalo, N.Y. 14216.

acrylic retainers may also be affected by the bending of the mandible during function.

b. Purpose of the Study

The author has had the experience of attempting to achieve the extreme accuracy required by fixed prosthetics. Regardless of how carefully techniques were employed, some adjustments were usually required to the bridgework, especially if the prosthesis crossed the mandibular midline. The addition of a stress breaker usually resulted in a good fit of the bridge, but although apparently accurate interocclusal recording materials were used, occlusal adjustments were common. The cause of the discrepancies observed seemed to be more than just the fault of materials and techniques. Deductive reasoning concluded that mandibular bending during wide open impression taking may have contributed to errors in interocclusal recording. The objective of this study is to evaluate mandibular transverse arch width changes in the mandible during border movements. Two age groups; adolescents (ages 13-15 years) and young adults (ages 21-28 years) comprised the test sample.

c. Research Questions

- 1) Is there a significant amount of change in intermolar width occurring with voluntary and assisted mandibular border movements?

2) Is the amount of intermolar width change that occurs with mandibular border movements age related?

3) Is the amount of intermolar change that occurs with mandibular movements related to the size (perimeter) of the mandible? (For this study, mandibular perimeter is defined as the distance from the middle of the tragus of one ear, following the soft tissue border of the mandible, to the middle of the tragus of the opposite ear.)

4) Is the amount of intermolar width change that occurs with mandibular border movements related to the range of motion?

d. Hypotheses

1) a. H_0 : There is no significant amount of intermolar width change occurring with voluntary unassisted maximum opening movements.

H_a : There is a significant amount of intermolar width change occurring with voluntary unassisted maximum opening movements.

b. H_0 : There is no significant amount of intermolar width change occurring with assisted maximum opening movements.

H_a : There is a significant amount of intermolar width change occurring with assisted maximum opening movements.

c. H_0 ! There is no significant amount of intermolar width change occurring with voluntary unassisted maximum protrusive movements.

H_a ! There is a significant amount of intermolar width change occurs with voluntary unassisted maximum protrusive movements.

d. H_0 ! There is no significant amount of intermolar width change occurring with voluntary unassisted maximum lateral mandibular movements.

H_a ! There is a significant amount of intermolar width change occurs with voluntary unassisted maximum lateral mandibular movements.

2. H_0 ! The amount of intermolar width change occurring with mandibular movements is not significantly less in adults (ages 21-28 years) than in adolescents (ages 13-15 years).

H_a ! The amount of intermolar width change occurring with mandibular movements is significantly less in adults (ages 21-28 years) than in adolescents (ages 13-15 years).

3. H_0 ! There is no significant correlation between the size (perimeter) of the mandible and the intermolar width changes occurring with border mandibular movements.

H_a ! There is a significant correlation between the size (perimeter) of the mandible and the

intermolar width changes occurring with border mandibular movements.

4. H_0 : There is no significant correlation between the range of motion of the mandible and the intermolar width changes occurring with border mandibular movements.

H_a : There is a significant correlation between the range of motion of the mandible and the intermolar width changes occurring with border mandibular movements.

Chapter 2

LITERATURE REVIEW

a. Mandible biomechanics

i. Symphysis development and function

The development of the mandible into an apparently rigid structure requires the fusion of the two halves of the developing mandible. The mandibular symphysis does not change from a syndesmosis to a synostosis until approximately one year post-natal⁴. Where hominids have a fused boney suture, thought to be an adaptation to a changing diet which required larger occlusal surfaces, most other mammals have a joint⁵. Larger grinding forces appeared to have increased functional stresses on the mandible pushing the posterior dentition medially resulting in the symphysis being compressed posteriorly and tensed anteriorly². An increase in incisal biting, resulting in greater shear forces at the symphysis, may have contributed to a symphyseal fusion adaptation. Also to achieve maximal occlusal force during unilateral biting, a fused symphysis may have allowed a greater utilization of the balancing side musculature⁶.

Debrul and Sicher have suggested that reinforcement of the mental symphysis resulted from stresses placed by muscles that move the mandible². Muscles, with their ability to decrease in length, act to move the point of attachment and insertion closer together. Because the muscles of the mandible have numerous sites of insertion and attachment, they act on the

mandible with a complex system of force vectors which may result in deformation of the mandible.

To understand how mandibular flexure occurs, the biomechanics of the muscles and their effect on the bone of the mandible must be examined.

ii. Bone characteristics

Evans described bone as a viscoelastic material that demonstrates the mechanical qualities of creep, plastic flow, stress relaxation, permanent flow, hysteresis, elastic recovery and elastic aftereffect⁷. Bone is a composite of an organic collagen component which is relatively soft and hydroxyapatite crystals which are very stiff and strong with a Young's modulus comparable to steel. Taken together as a composite, the strength of bone is greater than either hydroxyapatite or collagen, because the stiff component prevents the soft part from yielding and the soft component prevents the stiff one from brittle cracking⁸. Therefore, when sufficient force is applied to bone, bending will occur. Bone bending has been demonstrated, in a cadaver study by Grimm, to occur in the alveolar crest when orthodontic forces are applied to teeth⁹. Farah *et al.*¹⁰ developed a two-dimensional finite element model of a mandibular quadrant and examined stresses and displacements when a 100 N load was placed at various points in the quadrant. Bone bending, with the model provided, was demonstrated in the sagittal plane. Bone bending of the mandible, in the transverse plane, however, seemed to concentrate in the mental symphyseal area,

as demonstrated by Debrul and Sicher with the Stresscoat^b technique².

iii. Muscles of the mandible and their effects

Movements of the mandible are produced by the muscles of mastication, the suprahyoid, and the infrahyoid muscles. How the muscles apply stress to the mandible depends on the magnitude and direction of the muscular force vectors which, in turn, are dependent on the points of attachment and insertion and forces generated by individual muscles.

The masseter is a rectangular shaped muscle covering most of the lateral aspect of the mandibular ramus and is clearly divided into superficial and deep portions. The superficial portion of the masseter muscle originates from the maxillary zygomatic process and the anterior two-thirds of the zygomatic arch and inserts into the angle of the mandible and the lateral aspect of the ramus¹. Electromyographic (EMG) studies have shown high activity during clenching and protrusion, moderate to low activity with ipsilateral movement, and low activity during wide opening¹¹. Osborn and Baragar, using a computer assisted three-dimensional model of the jaw, predicted maximal muscle tension of the muscles of mastication. The force derived for the superficial masseter for maximal muscle tension was 27 Kg¹².

The deep portion of the masseter originates from the inferior border of the posterior third of the zygomatic arch

^b Stresscoat. Magnaflux Corp. Chicago, Illinois 61704.

and the inner aspect of the zygomatic arch and inserts into the upper portion of the lateral aspect of the mandibular ramus. The deep fibers are in a position to help retrude the mandible. According to Osborn and Baragars' model a maximum muscle tension of 19 Kg¹² was predicted for the deep masseter.

The medial pterygoid muscle is almost a mirror image of the masseter. The medial pterygoid originates from the medial aspect of the lateral pterygoid plate with a few fibers arising from the maxillary tuberosity and inserts onto the medial aspect of the mandibular ramus from just below the mylohyoid line to the inferior border of the mandible. The insertion of the medial pterygoid joins that of the masseter at the angle of the mandible to form the pterygo-masseteric sling which acts as a powerful elevator of the mandible¹. Electromyographic studies^{11,13} have indicated a high level of activity during clenching, contralateral, and protrusive movements. Low levels of activity were shown at wide opening and during ipsilateral mandibular movements. Medial pterygoid activity was similar to the superficial masseter except more activity was observed during mandibular movement. A maximum muscle tension of 26 Kg was predicted for the medial pterygoid.¹²

The temporalis is a fan shaped muscle divided by function into anterior, middle, and posterior portions. The temporalis originates from the lower temporal line, the temporal fossa below the temporal line, and the overlying temporal fascia to insert onto the medial aspect of the coronoid process and the

anteromedial border of the mandibular ramus¹. A high level of EMG activity was observed in the anterior temporalis during clenching, moderate activity during ipsilateral movements, and low activity with protrusion, contralateral, and wide opening movements. Nearly identical readings were observed for the superior head of the lateral pterygoid muscle^{11,13}. Middle and especially posterior temporalis fibers, because of their nearly horizontal orientation, were in a good position to retrude the mandible. The temporalis was also active in maintaining bilateral resting tonus when the subject was in an upright position¹. The predicted combined maximum muscle tension, when Osborn and Baragars' model was used, of the anterior, middle, and posterior temporalis, was 60 Kg¹². The temporalis muscle applied a greater force to the mandible than any other muscle.

The fan-like lateral pterygoid muscle consists of two distinct heads, the superior and inferior, having nearly reciprocal actions^{11,13}. The superior head originates from the entire roof of the infratemporal fossa, passes posteriorly and laterally, and inserts into the articular capsule, disc, and condyle^{1,13}. High EMG activities have been observed with clenching, especially in retruded contact. Moderate levels of activity were noted with ipsilateral movements while low levels were observed for wide open and contralateral movements. Activity levels of the superior lateral pterygoid closely paralleled those of the anterior temporalis muscle^{11,13}. Predicted maximum force levels also were similar

for the superior lateral pterygoid (12 Kg) and the anterior temporalis (17 Kg).

The inferior head of the lateral pterygoid muscle originates from the lateral aspect of the lateral pterygoid plate of the sphenoid bone and passes slightly upward, backward, and laterally to insert into the pterygoid fossa of the condylar neck¹. High EMG activity in the inferior pterygoid has been observed in protrusive, opening, and contralateral movements. Moderate to low activity was shown with ipsilateral movements while minimal activity was noted during clenching in retruded contact^{11,13}. Maximum muscle tension for the inferior pterygoid muscle has been predicted to be 27 Kg¹².

The digastric muscle is the only non-masticatory muscle to apply significant force to the mandible during mandibular movement¹². The anterior belly of the digastric muscle originates as an intermediate tendon at the greater horn of the hyoid bone. The tendon is a continuation of the posterior belly of the digastric which originates from the digastric notch on the temporal bone. The anterior belly inserts into the digastric fossa near the midline on the inner aspect of the mandible¹. The anterior digastric had the highest levels of EMG activity during wide opening and was also active during ipsilateral position and protrusion. Retruded clenching also caused high levels of anterior digastric activity as the muscle served an isometric function to protect the teeth in event of an unexpected rapid closing^{11,13}. A maximum muscle

tension of 11 Kg. was predicted for the anterior belly of the digastric¹².

Coactivation of the muscles that apply force to the mandible is essential for not only basic jaw movements, but also is important for fine control, stability of the mandible, and protection of the teeth. Simultaneous EMG activity of shortening and lengthening muscles allows coordinated movements when the mandible is subjected to a very complex system of force vectors.

b. Mandibular Flexure Studies

The inferior head of the lateral pterygoid muscle is reported to have the mechanical advantage, EMG activity^{11,13}, and maximum force levels¹² to aid in causing medial flexure of the mandible during opening and protrusive border movements (Figure 1). Other border movements may recruit other muscles¹, and varying degrees of distortion of the mandible may occur²⁵⁻²⁷.

Earlier, more qualitative studies, attempted to demonstrate that mandibular flexure did indeed occur.

In 1945, Gurdjian and Lissner¹⁵ attempted to demonstrate the adduction of the mandible under forces simulating the action of the lateral pterygoid muscles by coating a human mandible with Stresscoat, a clear, brittle coating which tends to crack under tension deformation. Cracks formed in the coating when the material was subjected to tensile strains of the order of magnitude of .0005 to .0015 inches per inch. Calibration strips of steel were used to determine the actual

sensitivity of the lacquer used. The calibration strips and the lacquer were applied at the same time under controlled temperature and humidity. Vertical hairline cracks appeared on each side of the mental trigone when the mandibles were subjected to stress simulating the contraction of the lateral pterygoid muscles. The cracks were predominately anterior to the mental foramen while very few hairline cracks in the Stesscoat appeared distal to the mental foramen.

The Stesscoat technique was later duplicated by Dubrul and Sicher² (1954) in a demonstration of the adaptive role of the mental protuberance to the forces applied by the lateral pterygoid muscles. Force was applied to a dried human mandible simulating the vectors applied by the lateral pterygoid muscles. The triangular bone mass overlaid upon the external aspect of the mandibular midline was demonstrated to act as a mechanical brace. The distortion was also measurable in vivo. The authors stated that the distance between the back molars was as much as a half millimeter less when the mandible was protruded than when it was at rest. No details of the in vivo methodology were presented.

A qualitative assessment of biting forces and the resulting distortion in the maxilla and the mandible were observed by Picton¹⁶ (1961) who utilized a dynamometer which employed a wire resistance strain gauge. The forces were recorded in 100 gm intervals to 2 kg. While biting forces were being applied, on the opposite side of the mouth, tooth movements were detected with the aid of wire resistance strain gauges. Small

pointers were cemented to transducers which were then attached to a rubber dam clamp. The pointers contacted the occlusal surfaces of the teeth adjacent to the clamped tooth. Any tilt of the clamped tooth caused distortion of the strain gauges. When the dynamometer and the rubber dam clamp apparatus were connected to a graphic recorder, a dynamic record of tooth movement and biting force was observed in thirteen of the fourteen test subjects in the mandible. Nine of the sample had movement of the test tooth in the maxilla. The tooth movement observed on the side of the mouth without any direct force was attributed to bone distortion since the movement occurred even when adjacent teeth were absent.

After establishing that the mandible did flex during mandibular movements, further studies attempted to determine the quantity of flexure that occurred. Most quantitative studies of mandibular flexure utilized either a graduated measuring device or some variety of electronic measurement. The following six studies utilized graduated measurement techniques.

- 1) A micrometer measuring apparatus was used by McDowell and Regli¹⁷, who in 1960, devised the first in vivo quantitative study to measure the decrease in mandibular width from the rest position to a forced protrusive and a wide open position. A sample of 20 dental students were randomly selected and metal splints were constructed to cover the occlusal, buccal, and lingual surfaces of their posterior teeth. A scissors-like measuring device was developed with a

gauge capable of detecting a .0005 inch dimensional change. Readings were then taken in the second molar areas for both maximum protrusion and maximum opening and the results recorded. The procedure was repeated three times for each motion with only the maximum reading recorded. The average cross-arch dimensional change at the second molar level on maximum depression of the mandible was 0.4 mm, and on forced protrusion, 0.5 mm. The greatest intermolar width change noted in the study was 1.5 mm on forced protrusion.

2) In 1967, Regli and Kelly¹⁸, attempted to determine the amount of mandibular flexure indirectly. No sample selection criteria were given for the sixty-two patients, who each had two impressions taken, one with the mandible fully depressed and the other with the mouth closed as far as the impression tray would allow. After casts were made from the impressions, resin occlusal templates were fabricated to cover the posterior teeth. A small indentation was made on the templates directly over the center of the occlusal surfaces of the first premolar and the second molar. These indentations were made to receive the styli of a modified scissor-like micrometer very similar to the instrument used by McDowell and Regli¹⁷ in 1960. The cross-arch width was measured with the templates on the cast for maximum opening and then the templates were placed on the corresponding cast for mouth closure. The average contraction in cross-arch distance at the premolar level was 0.03 mm, and at the second molar level,

0.09 mm. The largest change noted was 0.2 mm measured in one subject at the second molar level.

3) Mandibular flexure associated with only opening and closing movements was investigated by Goodkind and Heringlake³ in 1973. Twenty male dental students and 20 female dental assistants, selected on a volunteer basis, were used in the study. Stone casts, from mandibular impressions taken at the most closed position, were produced for each subject and intermolar widths were measured. Also, the range of opening of each subject from maxillary central incisor tip to mandibular incisor tip was determined. A metal clutch with a dial micrometer was then attached to posterior teeth of one quadrant. A projection arm from the micrometer was directed against the height of contour of the second molar on the contralateral mandibular quadrant. The subject was instructed to close to a rest position without touching the metal clutch attached to the posterior teeth. The micrometer was then zeroed and the subjects were asked to open as wide as possible. Slow opening movements to a wide-open position demonstrated progressively decreasing intermolar widths with recordings taken at maximum opening only. The mean amount of medial mandibular flexure in the second molar region was, 0.0768 mm, with a range from 0.0533 mm to 0.1092 mm. No correlation was found when mandibular flexure was compared to the range of opening or to intermolar widths. Gender of the subjects was not correlated. Reproducibility of results was demonstrated by duplicating the trials five times on the same

subject resulting in a standard deviation of 0.0096 mm. Testing was also repeated on the same patient on different days with nearly identical results.

4) Two of the reasons for the dentist to consider the implications of mandibular flexure during forced opening are its effect on fixed prostheses and on the periodontium of the abutment teeth. In a case study, Fischman¹⁹, in 1976, sought to determine by what amount various combinations of fixed prostheses would limit mandibular flexure. A 28 year-old woman, who required full coverage restoration of her mandibular dentition, participated in the study and acted as her own control. The teeth were prepared and cast copings were fabricated for all the mandibular teeth present. Receptacles for an engineering calliper with parallel arms were incorporated into the castings of the mandibular right first and left second molars. The amount of mandibular flexure that occurred with maximum opening, when no teeth were splinted, served as the control flexure. The amount of control flexure was 0.0339 ± 0.0056 mm which represented the amount of intermolar width change that occurred with wide open movements when no splints were in place. Four splints were cast; an anterior splint from canine to canine, left and right posterior splints, and a full mandibular splint. The anterior splint was also attached to the posterior splints with a precision attachment. The amount of mandibular flexure was determined for each fixed splint or combination of splints. Each test was repeated 15 times, and the difference in flexure

was determined. Inhibition of mandibular flexure appeared to have increased as more teeth were splinted and more rigid attachments used. Mandibular flexure, even with a full mandibular splint, was never completely inhibited.

5) Demarco and Paine²⁰, in a 1974 study of 7 men and 18 women, examined mandibular dimensional change that occurred with maximum opening movements from a different perspective. They attempted to derive a mathematical formula to describe mandibular bending versus percentage opening. Range of motion was determined by measuring, in centric occlusion and in a wide open position, the distance from the base of the nose to a mark placed on the chin. A calibrated, sliding rod gauge, was designed to span the mandibular arch at the first molars. The intermolar distance was recorded with the teeth in centric occlusion and again with mandible fully depressed. Measurements were expressed as percentages of the maximum interocclusal distance (100%) and as percentages of the maximum contraction of the mandible (100%). Thereafter, any random position of the mandible was plotted as per cent contraction versus per cent opening. The mean maximum opening of the 25 subjects was 52.5 mm while the mean medial contraction at the first molars was 0.78 ± 0.05 mm with a range of 0.6 mm to 1.5 mm. Plotting per cent contractions versus per cent openings showed that no change in intermolar width occurred until the subject reached 28% of maximum opening after which a "linear" correlation coefficient of 0.43 resulted.

6) Omar and Wise²¹, in 1981, examined mandibular flexure associated with muscle force applied in the retruded axis position (R.A.P.). The objective of the study was to measure the flexure that occurred when R.A.P. recordings were made with; a Lucia jig²², patient-applied muscle force, and chin-point guidance. Determination of mean medial flexure in wide opening movements was presented as a corollary to the study. Ten subjects, aged 18 to 36 years, with intact dental arches (excluding third molars) and free from obvious periodontal disease, were selected for the study. Splints were cast to cover the right mandibular posterior teeth. The measuring device consisted of a unilateral cap splint, projecting rod, crossbar, microcrew, and a dial indicator connected together with universal joints. The universal joints on the apparatus were tightened, the dial was zeroed, and rechecked again in five minutes for any changes. Five recordings of mandibular flexure were made during wide opening for each subject. A mean medial decrease of 0.093 ± 0.044 mm, with a range of 0.012-0.164 mm, was observed.

In an effort to achieve greater accuracy in measuring mandibular flexure, the following five studies utilized various electronic measurement techniques.

1) Siebert²³, in 1981, in a different approach, measured mandibular flexure by examining anterior guidance and physiologic tooth movement. Investigations on an unspecified number of subjects showed elastic deformation of the mandible even in the absence of occlusal contact. Physiologic movement

of single teeth during parafunctional movements were noted using inductive (non-contacting) displacement transducers placed in paraocclusal splints to which a modified Stuart pantograph^(c) was adapted. The greatest movements observed in horizontal and sagittal planes occurred with maximal protrusion. Maximum opening, in the horizontal plane was consistently 0.01-0.03 mm less than protrusion. When tongue pressure was applied to the teeth, movement was observed in the buccal direction perhaps indicating tongue activity in swallowing and speech may compensate for elastic deformation of the moving mandible. Three dimensional movements up to 0.06 mm were noted during occlusion.

2) Osborne and Tomlin²⁴, in 1964, constructed an intra-oral measuring device that utilized a variable capacitance transducer. A sample of 31 males and 9 females, ranging in age from 19 to 30, who all had good periodontal health with negligible tooth mobility, was tested. Silver cap splints similar to those used by McDowell and Regli¹⁷ were fabricated. Recordings were made at maximum opening, closure, extreme protrusion, and then back to their rest position with each series of motions being repeated three times. The maximum range of opening was also recorded on each subject. The average cross-arch dimensional change at the second molar level while the mandible was depressed as far as possible was 0.07 ± 0.013 mm, and on maximum protrusion was 0.09 ± 0.013 mm.

^c Stuart instrument and pantograph kit. Dr. Charles E. Stuart, P.O. Box 981, Ventura, Cal. 93003.

There appeared to be no statistical difference between the amount of flexure that occurred with maximum opening or protrusion. There was no correlation between the age of the subject and the amount of mandibular flexure. The transducer used in this study appeared to encroach on the tongue space.

3) Strain gauges were again used to determine intermolar width changes with various mandibular excursions by Burch and Borchers²⁵ in 1969. A strip of untempered beryllium-copper spring steel was adapted to fit between the right and left first molar teeth. The strain gauges were mounted, one above and one below the centre of the slightly upwardly bowed steel strip. The second strain gauge mounted on the underside compensated for any temperature differential. Leads from the transducer were attached to a polygraph recorder which would indicate any change in the convexity of the metallic strip. A sample of 10 subjects of unspecified gender, age, or periodontal health were requested to protrude and depress their mandibles fully, and to move their mandible into maximum left and right lateral excursions after the measuring apparatus was secured to the first molars. A decrease in mandibular arch width was noted in all 10 subjects with an average intermolar width change of 0.610 mm for protrusive, 0.438 mm for maximum opening, 0.243 mm for right lateral, and 0.257 mm for left lateral mandibular movements. Medial flexion was not maintained with prolonged mandibular depression or protrusion.

4) Bowman²⁶, in 1970, designed an instrument capable of detecting mandibular arch width changes that occurred when a variety of forces were applied to the mandible. Four females and 13 males, ranging between 21 and 38 years, with negligible tooth mobility, participated in the study. Aluminum castings similar to those used in previous studies^{17,24} were then fabricated to extend from the second premolar to the second molar teeth. The splints were connected by a transverse aluminum bridge at the second molar level joined in the centre by a locking jig. After the splints were cemented into position, the locking jig was removed and a U-shaped strain gauge transducer was secured across the gap to detect any transverse dimensional changes of the mandible. Before data collection, a waiting period of five minutes was allowed for the transducers to reach mouth temperature. The subjects were instructed to not breathe through their mouths nor to touch the intermolar measuring device with their tongues while they fully depressed their mandible, protruded as far as possible, and moved into maximum left and right lateral excursions. The mean medial flexion of the mandible when depressed fully was 0.290 mm. No distortion was observed until the mandible was depressed an average of 25 mm. Maximum protrusion gave a combined medial flexion of 0.637 mm. Adduction began immediately and was proportional to the amount of protrusion. Lateral movements caused a combined medial flexure of 0.113 mm. Minimal medial flexion was demonstrated during edge to edge biting.

5) Gates and Nichols²⁷, in a 1981 study, chose a more sophisticated approach for comparing mandibular arch width change with opening or protrusion. The measuring system to evaluate mandibular arch width change used a light-sensing photodiode. Changes in mandibular arch width were indicated by analyzing changes in the position of the light on the photodiode surface by relating light source location to voltage output. A linear variable differential transformer mounted extraorally measured millimeters of opening or protrusion. Ten males between 20 and 50 years of age, with a full complement of natural teeth and no evidence of periodontal disease, were chosen for the study. To protect the components from the oral environment, both the photodiode and fiberoptic strand were incorporated into aluminum casings. Flexible plastic tubing and insulating material also insured additional protection for the fiberoptic strand and electrical leads. Before mounting the LVDT-photodiode measuring system, each subject was administered an antisialogogue to reduce saliva flow. Resting values were determined for the subjects representing non-deformed mandibles. Subjects were instructed to move their mandible in a sequence of movements; maximum opening and closure, sustained opening (5 seconds), maximum protrusion and retrusion and sustained protrusion (5 seconds). The recording sequence was repeated five times for each subject. Data received from the LVDT and the photodiode was stored on magnetic tape, processed by an analog to digital converter, analyzed by computer and graphed by a digital

plotter. A medial flexure ranging from 0 to 0.3 mm was recorded for maximal opening and 0.1 to 0.5 mm for maximal protrusive movements. No means were given for the entire sample. With opening movements, no arch width changes were noted until subjects opened 20 mm, but a linear relationship was not observed between opening and mandibular flexure thereafter. Arch width changes also appeared to be maintained with both sustained opening and protrusion.

Gates and Nichols' measuring technique, as in others^{20,24-26} spanned the tongue. Radical changes were noted when the tongue made any contact with the measuring apparatus.

c. Summary and Critique of Flexure Studies

After examination of the data from the preceding studies, several factors become evident; a relative large variation in results, little effort to standardize the generally small size of the samples, and experimental techniques may not have achieved adequate accuracy by introducing an excessive number of variables. Measuring apparatus used often appeared to have too many moving parts, was too large or heavy, needed excessive time for temperature compensation, or required drug use to prevent moisture problems with electrical connections. Little attention was given to the effect of the inferior posture of the tongue during testing. Also the use of relatively heavy extrinsic forces on the participant's mandible and having subjects sustain border positions may have yielded biased data.

d. Design Parameters

To accurately measure flexion of the mandible in the transverse plane, the measuring apparatus must be attached to hard immovable tissues and offer little or no resistance to displacement. The only non-invasive option for anchorage is tooth structure with the mandibular first permanent molars as the first choice since the second molars may not have been completely erupted in an adolescent sample.

Teeth are attached to bone via the periodontal ligament and, if enough force is applied, can be moved. In normal function, movement of teeth is inhibited by the fluid in the periodontal space²⁸. The proteoglycan content of the gel-like tissue fluid surrounding the teeth is nearly incompressible when teeth are subjected to light intermittent forces^{28,29}. Instead, the force is transferred to the alveolar bone and to the body of the mandible where bone bending can occur²⁸. If the force is of sufficient duration and magnitude the fluid is expressed into the adjacent bone and early orthodontic tooth movement commences.

A clinically applicable, non-invasive approach to study design would be desirable. No radiographs, impressions, drug use, or even enamel etching should be needed in determining cross-arch dimensional change. When border movements would be required, subjects should be instructed to move their mandibles in each motion as much as possible without causing pain. A minimum of time, should be required for each border

movement to create as little stress as possible on the muscles and ligaments of the temporomandibular joint.

Chapter 3

MATERIAL AND METHODS

Determination of intermolar width change occurring with border movements was achieved by the construction of a strain gauge transducer capable of detecting mandibular dimensional changes in the transverse plane. This device, with an activating force well below that required to move the teeth in their sockets, was attached to the mandibular first molars. Forced (assisted) opening movements were also evaluated using a coiled spring device.

a. Sample

The fifty-eight subjects in this study were divided into two age groups; twenty-seven adolescents (aged 13-15 years) and thirty-one young adults (aged 21-28 years). The age grouping was chosen to see if differences in mandibular flexure occurred with different ages. In addition, the age groups had the greatest potential for good periodontal health and intact dental arches. Data produced by the adolescent sample may have been of interest to orthodontics since most orthodontic patients were within the age range of the subsample. Adolescent subjects were recruited from the Division of Pediatric Dentistry, Faculty of Dentistry, University of Alberta. The adult portion of the sample were all third or fourth year dental students. Necessary approvals and consent forms (Appendix A) were obtained. The distribution of subjects for age and gender is detailed in Table 1.

GENDER	AGE		TOTAL	PERCENTAGE
	13-15	21-28		
Male	15	26	41	70.7%
Female	12	5	17	29.3%
Total	27	31	58	100%

Sample Distribution for Age and Gender

Table 1

All subjects had Angle class I molar relationships, intact dental arches, minimal tooth mobilities (periodontal index of ≤ 1), and no overt signs of periodontal disease or temporomandibular joint dysfunction.

b. Procedure

i. Measuring instrument design and fabrication

For the measuring apparatus to be accurate, the force applied to the tooth structure must be less than that required to move teeth in their sockets. A loading force of less than 20 grams applied during the relatively short testing time (30 minutes) was chosen as previous studies have shown that immediate movement of a multirooted tooth requires between 100-500 grams of force^{26,30}. Any additional force applied to the anchor teeth was from the weight of the transducer. The weight of the largest transducer was less than 5 grams, which,

divided between the two anchor teeth, applied a negligible force.

The cross-arch measuring instrument was made of stainless steel shim-stock, 0.5 inches wide and 0.015 inches thick, designed to fit around the facial surfaces of the mandibular teeth (Figure 2). Four 300 ohm, bonded metallic strain gauges^(d), were attached to the anterior portion of the stainless steel shim with a methylcyanoacrylate adhesive^(e) (Figure 3). The strain gauges were then covered with a xylene polyurethane coating^(f), for protection from the oral environment. The configuration of the strain gauges was to allow for detection of movement in the transverse plane relative to the face. Four strain gauges were used to form a "full bridge" to obtain maximum sensitivity and to compensate for any temperature differential³¹. No waiting period was required for the transducer to reach the ambient temperature of the oral cavity. The apparatus was attached to the middle of the buccal surface of the mandibular first molars as far gingivally as possible via a threaded ball link^(g) (Figures 2,4).

^d MM 062, MM Inc., Raleigh North Carolina, USA. Distributed in Canada by Intertechnology, Inc., Don Mills, Ont. M3B 2X7.

^e M-Bond 200, Measurements group Inc., Raleigh, N. Carolina 28711.

^f M coat-A, Measurements Group Inc. Raleigh North Carolina 28711.

^g Du-bro 2-56, Du-bro Products Inc., Wauconda, Illinois 60084.



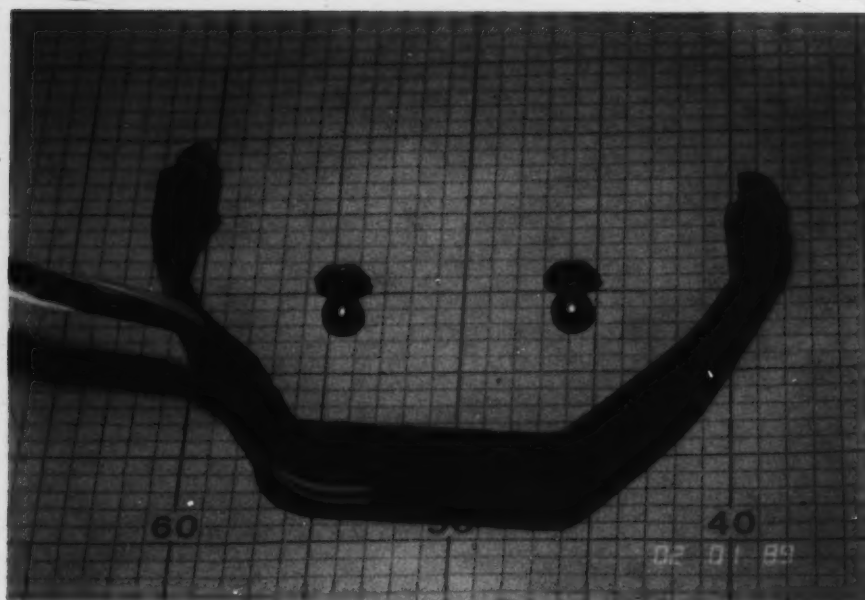
Mandible Transducer in Oral Cavity

Figure 2



Bonded Metallic Strain Gauges

Figure 3



Ball/Socket Attachment

Figure 4

The ball link consisted of a teflon socket and a steel ball arrangement. The teflon socket was attached to the ends of the stainless steel shim with a structural adhesive^(h) while the steel ball was attached to the tooth structure with glass ionomer cement⁽ⁱ⁾. The steel ball was smoothed and the opening to the teflon socket was widened to allow freedom of movement and to establish as close to a point contact as possible between the two elements. The completed measuring apparatus, with strain gauges, ball links, and a "quick-connect" wire lead, was referred to as a mandible transducer.

The transducer was then connected to a Vishay strain conditioner^(j) to provide accurate amplification.

A strip chart recorder^(k) was also connected to the strain conditioner to provide an analog backup record of mandibular flexure. Any change in voltage resulted in a deflection from the zero line which represented a medial or lateral mandibular flexure. The strip chart record also provided a way to confirm positional stability of the anchor teeth. Starting and finishing testing at the zero line indicated lack of tooth movement from the preload force.

^h Speedbonder 324, Loctite Inc. Newington, CT. 06111.

ⁱOrmco Inc. Glenora, Cal. 91740.

^j 2100 series, Vishay Inc., Distributed in Canada by Intertechnology Inc., Don Mills, Ont. M3B 2X7.

^k Model 585, Omega Engineering Inc., Stamford, Ct. 06906.

An attached digital multimeter⁽¹⁾ provided a visual reading of voltage changes. The multimeter also provided a way of measuring the preload of the transducer which represented the grams of force against the mandibular first permanent molars. The preload force was adjusted by bending the lateral portions of the transducers (Figure 2) to be less than 20 grams. Analog signals, representing voltage in one channel of data, travelled through a connecting box and then to an analog/digital converter^(m). After passing through the A/D converter, the signals, now in bit form, were input to a personal computer⁽ⁿ⁾ where, with the aid of a computer program, the data was converted into millimeters of mandibular flexure and stored on 5 1/4 inch floppy disks (Figure 5).

Opening and closing movements of the mandible in the sagittal plane were recorded by a mandibular Kinesiograph^{(o),32}. Analog data from the Kinesiograph followed the same path as that of the mandible transducer and made up a second channel, to be ultimately converted into millimeters of opening. Thus, with both signals simultaneously being received, it was possible to get a dynamic record of opening versus mandibular flexure. A flow

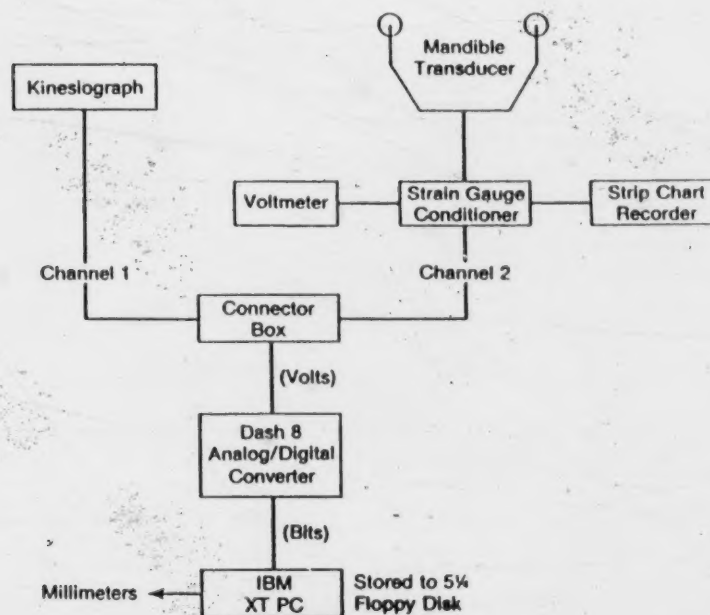
¹ Model 22-188, Intertan Inc., Barry, Ont. L4M 4W5.

^m Dash-8, Intertechnology Inc. Don Mills Ont.

ⁿ IBM XT PC, International Business Machines, White Plains, N.Y. 10604.

^o K-5 Model, Myotronics Inc., Seattle, Wash 98101.

chart of the mandible transducer/Kinesiograph measuring, data conversion, and analyzing system is given in Figure 5.



Flow Chart of Mandible Transducer/Kinesiograph
Data Conversion/Analyzing System

Figure 5

A coil spring device was also fabricated to apply an assisted jaw opening force (Figure 6).



Coil Spring for Assisted Opening

Figure 6

Stainless steel projecting arms were attached to coil springs. The tips of the arms were covered with a soft plastic coating to protect the maxillary and mandibular anterior teeth. The spring was compressed and inserted into the subject's mouth to simulate the force applied to the mandible during dental procedures such as impression taking. The device was designed to apply approximately 1 kilogram of force when the subject opened between 35-70 mm. A coil spring was used to provide a relatively constant force over the range of opening of the subjects. The 1 kilogram value was determined by suspending weights from the author's mandibular

incisor teeth until the force perceived was equivalent to that applied during a mandibular impression.

The metal of the coil spring device was non-magnetic so as to not influence the magnet attached to the mandibular incisors nor to interfere with the magnetic sensors on the Kinesigraph framework.

A prototype transducer was fabricated for the pilot study. Magnets of varying strengths were moved within 2 mm of the strain gauges with no effect on the data being received from the transducer. The stainless steel transducer also did not appear to affect the Kinesigraph readings.

All subjects were tested by the author.

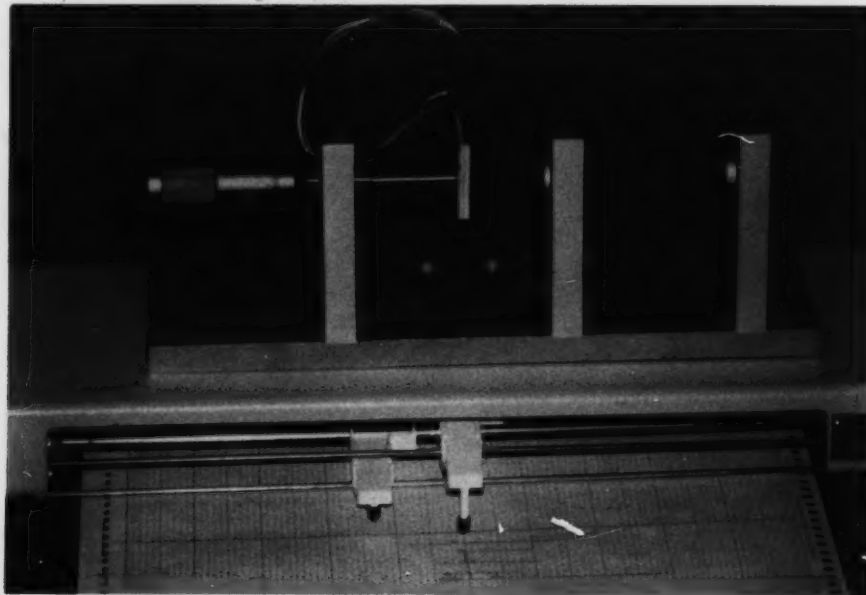
ii. Calibration

A prototype mandible transducer was fabricated and calibrated. In a bench test (Figure 7), the transducer was attached to a non-rotating micrometer^(P) accurate to 0.0007 inches, and systematically elongated and compressed in increments of 0.005 inches. Output in volts was represented on the strip chart as displacement in inches. Voltage excitation was set at 6.82 volts with the gain set at 1.30 volts. The full scale, displayed as a 5 inch displacement on the strip chart recorder, was 2 volts indicating a 0.1 inch transverse change in dimension at the ends of the transducer. The calibration was repeated two times in tension and once

^P Mitutoyo Inc. Tokyo, Japan. Distributed in Canada by MTI Canada, Mississauga, Ont. L5R 3J5.



with compression. The data were reproducible with both compression and tension.



Mandible Transducer Calibration

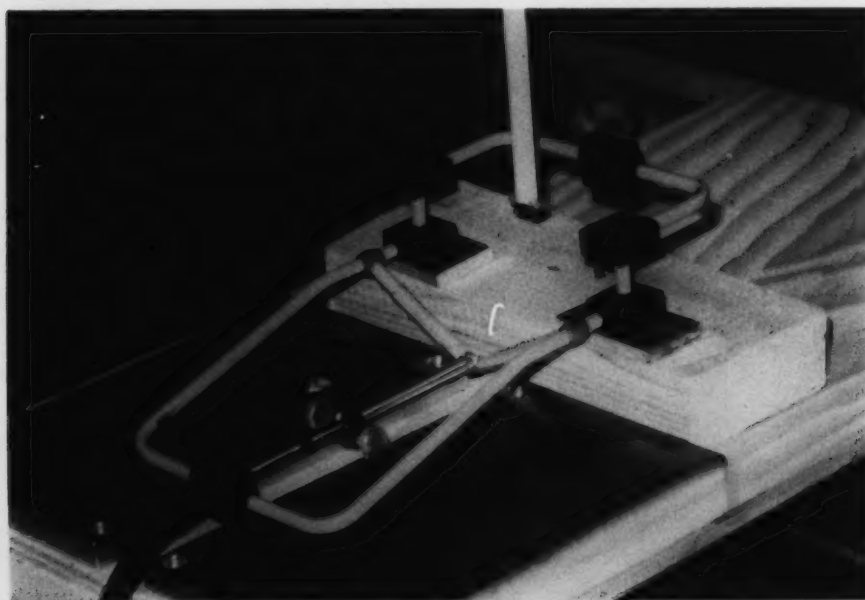
Figure 7

The transducer always returned to its undeformed state after testing. Various preloads (under 100 gms), adjusted by bending the large portion of the radius of the transducer, did not affect calibration. The preload voltage was also determined.

Transducers were fabricated with the wire leads departing the strain gauges at right angles to the anterior surface of the transducer. Calibration figures for the transducers are given in Appendix B. The dimensions of the mandible transducers are detailed in Appendix C.

Calibration of the Kinesiograph was more difficult than with the strain gauge transducers. At the outset, all

mandibular border movements were to be recorded with the Kinesiograph. Bench testing, however, demonstrated "cross-talk" between the sagittal, A/P, and lateral channels. The Kinesiograph records mandibular movements in three planes of space by detecting changes in magnetic flux, when, a rare earth magnet, mounted on the mandibular incisors, is moved relative to sensors mounted on a framework attached to a subject's head. To bench test the Kinesiograph, the framework was stabilized and isolated from magnetic matter, while the magnet, attached to the end of a teflon rod, was systematically moved relative to the magnetic sensors (Figure 8). The only channel giving consistent results was that of the sagittal plane.



Kinesiograph Calibration

Figure 8

The model of Kinesiograph used in the study was not digital. The model was designed to record mandibular movements by taking a Polaroid⁽⁹⁾ photograph of the mandibular trace on the oscilloscope. For this study, however, a computer program was written to determine voltage changes with movement in the sagittal plane, and to convert, with the aid of the analog/digital converter and a computer, the signal to millimeters of opening.

The Kinesiograph was individually calibrated for each subject to reduce measurement error. The voltage output for a subject was set at zero by moving the oscilloscope trace to the centre of the x/y reference axis. The subject's interincisal maximum opening, as measured by a Boley gauge was entered into the computer (Figure 9).



Interincisal Measurement

Figure 9

⁹ Polaroid Corp., Cambridge, Mass. 02139.

Recordings over 5 volts exceeded the range of the Kinesiograph oscilloscope screen. The maximum opening trace observed was compared with the Boley gauge measured value and the Kinesiograph framework was adjusted until the readings coincided. Keeping the subject's head in an upright posture was essential, as variations in readings occurred when the subject moved their head to other positions. A calibration factor was derived by the computer program to convert the voltage reading being input to the computer to millimeters of opening. The maxima of the other border movements (left lateral, right lateral, and protrusive), were directly measured by hand with a millimeter ruler and entered into the computer when the respective border movements were made. Each border movement was measured three times and averaged to the nearest millimeter.

The mandibular perimeter was measured with a flexible tape from the tragus of one ear along the soft tissue perimeter of the mandible to the tragus of the opposite ear. The perimeter measurement was repeated five times and averaged. The soft tissue mandibular perimeter was measured to the nearest 0.5 cm.

The final input, therefore, only collected data from two channels when the subject was undergoing wide opening movements. Because of calibration errors detected with movements other than wide opening, only data from this transducer channel was automatically input.

iii. Data collection

The test protocol for determining intermolar width changes with mandibular border movements is detailed in Appendix D. See Figure 10 for illustration of the testing apparatus in place.



Mandibular Transducer/Kinesiograph Testing Apparatus

Figure 10

Chapter 4

RESULTS

A pilot study with a sample of 2 adults, aged 27 and 44 years, and an 8 year old child was run to determine standard deviations and required sample size (Appendix E). Results were consistent with previous studies^{2,3,16-21,24-27}. One subject were tested on the same day and two days later. Mean test results were identical (0.33mm) for wide open movements and nearly the same for the other border movements ($\pm 0.03\text{mm}$) on the different testing days. The standard deviation for the different border movements ranged from 0.01-0.05mm. Manually assisted opening produced a larger standard deviation of 0.15 which appeared to indicate that the amount of intermolar width change was dependent on the amount of force applied. Subsequently, the standardized forced-opening coil spring device was fabricated.

A distribution table of the test sample is detailed in Appendix F. The independent variables of the subjects used were age (year/month), mandibular perimeter, maximum opening, maximum left lateral, maximum right lateral, and maximum protrusive movements.

Individual trial means of intermolar width change were calculated for: forced opening, maximum left lateral movements, maximum right lateral movements, maximum protrusive movements, and maximum opening for adolescents and young adults (Appendix G). Reproducibility of results was observed

by the similarity of the means of intermolar width change within the five trials of testing.

Means, variance, standard deviation, standard error of the mean, and minimums and maximums of intermolar width change were determined for the subjects tested (Table 2).

Border Movements	Forced Opening (assisted)	Left Lateral	Right Lateral	Protrusive	Vol. Wide Opening
ENTIRE SAMPLE (mm)					
Mean	-.140	-.105	-.091	-.210	-.285
Variance	.012	.006	.003	.011	.018
St. Dev.	.108	.079	.058	.104	.135
Minimum	-.56	-.40	-.31	-.51	-.63
Maximum	.00	.00	.00	-0.01	.00
S.E. Mean	.014	.010	.008	.014	.018
ADOLESCENTS					
Mean	-.156	-.097	-.091	-.259	-.285
Variance	.009	.004	.002	.004	.005
YOUNG ADULTS					
Mean	-.125	-.112	-.092	-.167	-.285
Variance	.004	.005	.002	.002	.017

Description of Intermolar Width Change Data

Table 2

Values were determined for each border movement for the entire sample and for the two age groups. A significant amount of intermolar width change was recorded for each variable. Voluntary wide open movements produced the greatest amount of mean medial intermolar width change (-0.285mm for

adolescents and young adults), followed in descending order, by protrusive (-0.259mm adolescents, -0.167mm young adults), assisted forced open (-0.156mm adolescents, -0.125mm young adults), left lateral (-0.097mm adolescents, -0.112mm young adults), and right lateral (-0.091mm adolescents, -0.092mm young adults) movements.

Wide open border movements for young adults showed the most variance (0.017mm). Lateral right movements for both adolescents and young adults and protrusive motions for young adults subjects showed the least variance (0.002mm).

F tests and Scheffe multiple comparison tests were run comparing intermolar width change to the age of the subjects tested. Repeated measures were adjusted (Greenhouse-Geiser adjustment) and a summary table of F-ratios was derived (Table 3).

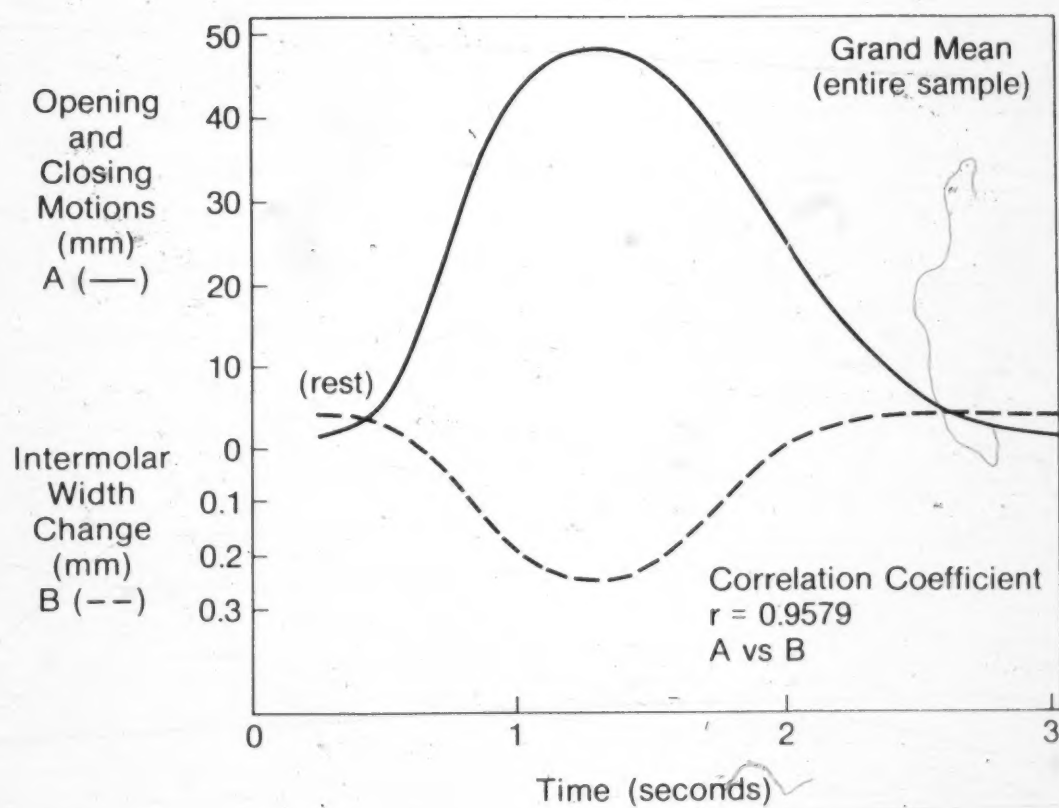
	Mean Square Hypothesis	Mean Square Error	F-Ratio	Degrees of Freedom Hypothesis	Degrees of Freedom Error	Probability
Univariant Grand Mean	7.45	0.02	345.68	1.0	55.0	0.220E-24
Univariant Age	0.05	0.02	2.27	1.0	55.0	0.1358
Univariant Type	0.41	0.00640	63.76	5.0	269.0	0.105E-42
Greenhouse-Geiser Adj:	0.41	0.00640	63.76	3.2	171.8	0.769E-28
Univariant Age/Type	0.02	0.00640	3.31	5.0	269.0	0.00640
Greenhouse-Geiser Adj:	0.02	0.00640	3.35	3.2	171.8	0.01914

Table 3

Summary Table of F-ratios

Calculated values demonstrated that age must be associated with the type of movement to be significant at $p \leq 0.05$. Age alone was not significant with a probability level of $p = 0.1358$, but age/type was significant at a level of $p = 0.0064$, meaning, that the amount of intermolar width change occurring with border movements was related to age for some movements and not others. Adolescents had statistically more intermolar width change than young adults with (assisted) forced opening and protrusive, less intermolar width change with left lateral, nearly identical amounts for right lateral, and exactly equal amounts of intermolar width change for wide open movements.

An overlay plot representing the dynamic association of opening and closing movements to intermolar width change over time for the entire sample is illustrated in Figure 11. The upper part of the plot (solid line A) represents the means of opening and closing motions while the lower plot (dashed line B) represents the progressive mean medial intermolar width change occurring with opening movements.

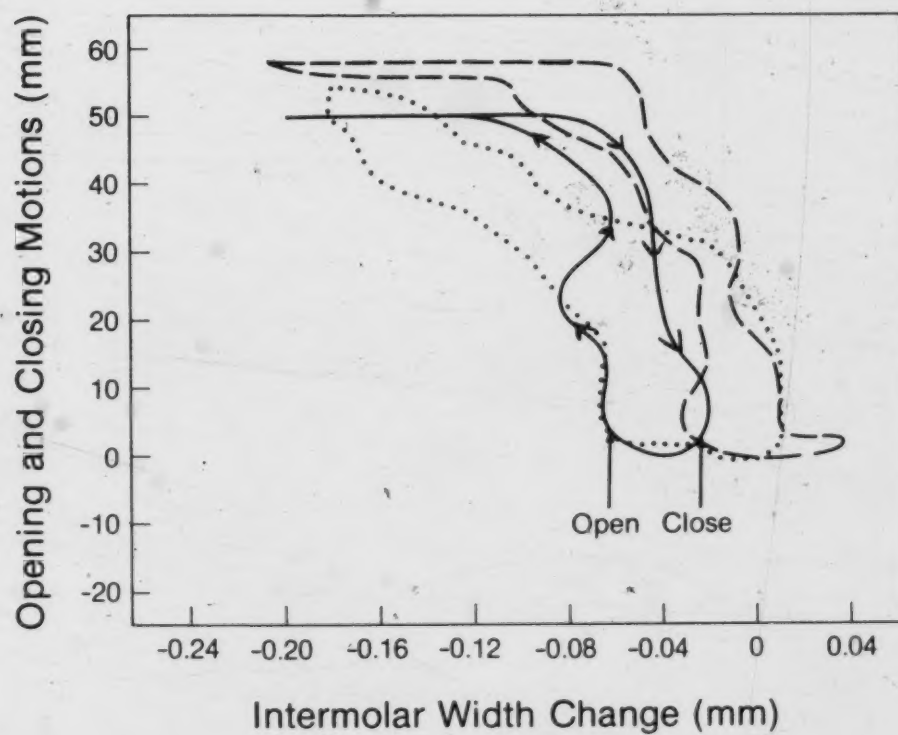


Dual Overlay Plot

Figure 11

A Pearson correlation coefficient of $-.9579$ was calculated for voluntary wide opening and closing motions (Kinesiograph channel A) and intermolar width change (mandible transducer channel B). Mean medial intermolar width change occurred with less than 10 mm of opening, continued to increase in relation to opening, plateaued at a maximum value corresponding to static maximum opening, and decreased as closing occurred to a resting state. During the opening and closing sequence data was collected 755 times within the 3.2 seconds allotted. The mean time for the opening and closing sequence was 2.3 seconds.

Subjects appeared to have individual flexure signatures which were reproduced with repeated trials. When intermolar width change was plotted against opening and closing motions a distinct pattern for each subject tested was observed. An example of three distinct patterns from three subjects is illustrated in Figure 12. The four remaining signatures of the five trials for each of the three subjects are illustrated in appendix H. A very reproducible pattern similarity is evident from the individual trials for each subject.



Three Representative Mandibular Flexure Signatures

Figure 12

For the sake of clarity the signatures are not superimposed.

Pearson correlation coefficients and levels of probability were also calculated for the mean intermolar width change occurring with border movements, mean maximum range for each border movement, and the means of the mandibular perimeters. Significant correlation coefficients and levels of significance are illustrated in table 4 and further expanded in Appendix I.

**Intermolar Width Change with Associated Border Movements
Maximum Ranges of Motion
Mandibular Perimeter**

**Pearson Correlation Coefficients
(entire sample)**

	FO	LL	MX/LL	LR	MX/LR	PR	MX/PR	WO	MX/O	MDP
FO		0.300**		0.416***		0.417***		0.333**		0.271*
LL				0.587****		0.457****				0.267*
MX/LL				0.229*	0.735****		0.403**			
LR						0.498****		0.295**		
MX/LR							0.383**			
PR								0.548**		0.308**
MX/PR										-0.309**
WO										
MX/O										0.378**
MDP										

r values, $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***), $p < 0.000$ (****)

Border Movements: FO = Forced Opening (Assisted), LL = Left Lateral

LR = Right Lateral, PR = Protrusive, WO = Wide Open

MDP = Mandibular Perimeter

MX/O, MX/PR, MX/LL, MX/LR = Maximum Range of Motion

**Significant Correlation Coefficients
and Levels of Significance**

Table 4

Most movements showed modest correlations between each other with a probability level at $p \leq 0.05$ therefore rejecting the null hypothesis. The largest correlation coefficient between dissimilar movements was $r = .548$ correlating intermolar width change for maximum opening and protrusive movements. The only insignificant correlation between movements was the intermolar width change correlation between maximum opening and lateral left border movements ($r = .1335$, $p = 0.155$, App. I).

The mean perimeter size of the mandible, using the methodology in the study, was 32.0 cm for the entire sample, 31.0 cm for the younger portion, and 33.5 cm for the older portion of the sample. Calculated Pearson correlation coefficients (Table 4) showed the mandibular perimeter means were weakly correlated with the means of forced opening, left lateral, and protrusive movements and also with the means of the maximum opening values. Interestingly, a negative correlation (-0.309 at a level of $p = .01$) was determined for the means of the maximum range of protrusive movements when compared with the means of the mandibular perimeter. Conversely, a positive correlation ($.378$ at a level of $p = .01$) was noted between the means of maximum opening and the means of the mandibular perimeter. No significant correlation was noted for means of the range of motion versus the means of intermolar width change. The only exception was a relatively weak correlation between intermolar width change for lateral right motions and the maximum left range of motion ($r = .229$, $p = .046$).

Table 5 describes the data regarding the maximum range of motion for wide open, protrusive, left lateral, and right lateral border movements for the entire sample, adolescents, and young adults.

(mm)	LL	LR	PR	WO
ENTIRE SAMPLE				
Mean	11.2	10.9	8.9	51.5
Variance	4.05	4.53	3.10	37.12
Minimum	7.0	7.0	4.0	38.0
Maximum	15.0	16.0	12.0	70.0
S.E. Mean	0.271	.287	.237	.800
ADOLESCENTS				
Mean	11.3	11.2	9.4	51.5
Minimum	7.0	7.0	7.0	41.0
Maximum	15.0	16.0	12.0	60.0
YOUNG ADULTS				
Mean	10.9	10.6	8.4	51.4
Minimum	7.0	8.0	4.0	38.0
Maximum	15.0	15.0	12.0	70.0

Description of Maximum Range Data

Table 5

Measurement error in determining range required rounding figures to the nearest millimeter. Therefore, the mean maximum range for both left and right lateral motions was 11 mm for both adolescents and young adults, whereas the mean maximum range for protrusive movements was 9 mm for adolescents and 8 mm for young adults. Mean maximum range for wide open movements was 51 mm for both adolescents and young

adults. Wide open motions had the widest range of maximum values, ranging from 38 to 70 mm. Mean maximum range for all motions appeared slightly larger for adolescents than young adults. Mean maximum ranges for left lateral, right lateral, protrusive, and wide open motions appeared to have no significant correlations with the mean amount of intermolar width change that occurred with border movements, except, as noted earlier, between mean intermolar width change for lateral right motions and the mean maximum range of lateral left motions. Significant correlations, however, were noted between the maximum range for lateral left and lateral right motions ($r = .735$, $p = .000$), protrusive and lateral left ($r = .403$, $p = .001$), protrusive and lateral right ($r = .383$, $p = .002$), protrusive and mandibular perimeter ($r = -.309$, $p = .011$), and wide open and mandibular perimeter ($r = .378$, $p = .002$).

A Scheffe multiple comparison algorithm was run to determine significant differences between means of intermolar width change for wide open, protrusive, forced open (assisted), left lateral, and right lateral motions for the entire sample (Table 6). A significant difference, denoted by *, between assisted (forced open) and voluntary wide open motions was determined. Significant differences were also noted between intermolar width change means for assisted (forced open), lateral left and right motions, and protrusive motions. An additional Scheffe multiple comparison was run including age (Appendix J). A significant difference between

assisted and voluntary wide opening was noted for both adolescents and young adults. Voluntary wide open motions consistently achieved more intermolar width change than forced opening. There was no significant difference between adolescents and young adults for assisted (forced) opening.

	WO	PR	FO	LL	LR
WO		0.07*	0.15*	0.18*	0.19*
PR			0.07*	0.11*	0.12*
FO				0.04	0.05
LL					0.01
LR					
MEAN (mm)	-0.29	-0.21	-0.14	-0.10	-0.09

HYPOTHESIS TERM FOR COMPARISONS: TYPE OF MOTION

VARIABLE: INTERMOLAR WIDTH CHANGE

REQUIRED DIFFERENCE: 0.05

OBSERVED DIFFERENCE: TABLE

* = SIGNIFICANT DIFFERENCES BETWEEN MEANS

ALPHA = 0.050000, S.E. = 0.02, D.F. = 269.00

Scheffe Multiple Comparison

for the Entire Sample

Table 6

Chapter 5

DISCUSSION

The model design of this study was approached differently than previous investigations of intermolar width change associated with mandibular movements. To make the study more statistically significant, an increased sample size, comprising two age groups; adolescents and young adults, was studied. No known previous study tested adolescents. Standardization of the sample was attempted by limiting subjects to those having an Angle Class I molar relationship. Gender and race were not entered into the statistical calculations because of insufficient numbers of representative subjects. The measurement technique differed from any previous studies. By measuring the intermolar width change from the buccal surfaces of the first molars, the tongue assumed a more natural posture with respect to mandibular movement. An attempt was also made to correlate range of motion and mandibular size with intermolar width change. The role of passive constraints was investigated by measuring intermolar width change when the mandible was forcibly depressed with the mandibular muscles relaxed.

The means of medial flexure observed with border movements were consistent with several previous studies^{17,25-27}. However, means for medial intermolar width change occurring with wide open movements were consistently greater than that of protrusive movements, contrary to earlier findings^{17,24-27} (Table 7).

	n	wide open mm	protrusive mm	L.L. mm	L.R. mm
McDowell and Regli (1960)	20	.04	.05	--	--
Regli and Kelly (1967)	62	.09	--	--	--
Goodkind Herringlake (1973)	40	.08	--	--	--
Fishman (1976)	1	.03	--	--	--
Demarco and Paine (1974)	25	.78	--	--	--
Omar and Wise (1981)	10	.09	--	--	--
Osborne and Tomlin (1964)	40	.07	.09	--	--
Burch and Borchers (1969)	10	.44	.61	.24	.25
Bowman (1970)	17	.29	.64	.11	.11
Gates and Nichols (1981) (range only)	10	0-3	.1-5	--	--
current study	58	.29	.21	.11	.09

Summary table of intermolar width change means as reported
associated with border movements reported in the literature
as compared to current study

Table 7

The variability of results may have been due to measuring and recording techniques. An inferiorly positioned tongue, required by a number of earlier measuring techniques^{20,24,25}, may have directed more force to the symphysis thus increasing the flexure observed with protrusive movements.

Instruction to each subject regarding border movements may have also affected the amount of mandibular flexure observed, in that slow, sustained border movements may have realized larger amounts of intermolar width change than what occurred in the 3.2 seconds given for border movements in this study. The amount of force applied when moving the mandible into border positions may have also influenced mandibular flexure. Subjects, in this study, were instructed to undergo maximum border movements without experiencing discomfort or pain to lessen the possibility of temporomandibular joint injury.

Age alone did not appear to influence the amount of intermolar width change when considering all movements for the entire sample. When the type of border movement was included in the calculations with age, a significant influence on intermolar width change was noted.

Numerous factors may have influenced the differences between the two age groups tested. Adult patients usually have more bony mass, especially in the chin. Adults may also have denser, more rigid bone than adolescents. Muscles in adults, in comparison to adolescents, may be larger and thus stronger. The stronger mandibular depressing muscles may compensate for any bone rigidity thus giving equivalent

flexure with wide opening and possibly lateral motions for both age groups. Bone appears to compensate for any additional stresses applied in accordance with Wolff's Law. Ligamentous constraints in the TMJ may influence the amount of mandibular flexure and may change with age. The relatively large variance in flexure with young adults, in comparison to adolescents, with wide open motions (.017 versus .005) may have been influenced by differences in joint mobility. Adolescents generally appear to exhibit a wider range of joint mobility.

One subject with hypermobility and clicking during opening movements was tested but not included in the study. While undergoing opening movements negligible intermolar width change was observed. Perhaps taut ligaments are required to initiate stretch reflexes to precipitate increased muscular contraction during opening. Also, the lack of mechanical constraints due to lax ligaments could have influenced the force system affecting the subject's mandible.

Significant correlations between the amounts of intermolar width change occurring with different border movements indicates that, for the entire sample, the more the mandible would distort when moved in one direction, the more it would distort when moved in another. The highest correlation for border movements was between wide open and protrusive motions which may indicate that similar stresses are being applied to the mandible during both movements. Therefore, in terms of preventing mandibular distortion, the mandible should be

closed as far as possible and not protruded during impression taking.

In this study, the role of ligamentous constraints in relation to mandibular flexure was tested with a forced opening device. A statistical difference was noted between assisted (forced) opening and voluntary wide opening. The voluntary wide opening values were consistently greater than the assisted values with both adolescents and young adults. This finding seemed to indicate the importance of muscles causing intermolar width change with voluntary wide opening as opposed to assisted wide opening in which subjects were instructed to relax their muscles during opening. True relaxation of the muscles, however, was not possible without a skeletal muscle blocker. Also the inherent viscoelasticity, and the initiation of stretch reflexes, in the jaw closing muscles may have prevented a truly passive motion. The force level used with the spring device was arbitrarily set at 1 kilogram which appeared to be consistent with that used during impression taking. Higher levels of force, however, may have produced much greater mandibular flexure values, as was observed during the pilot study.

Examination of the dynamics of opening and closing motions and their relation to intermolar width change may possibly be evaluated with the use of the signatures obtained for opening and closing motions (Figure 12). In early opening, the condyle rotates while being restrained by the temporomandibular ligament. Jaw opening muscles apply forward

and downward/backward force vectors¹⁴. Electromyographic studies have shown that the primary muscles involved in opening are the inferior lateral pterygoids (forward vector) and the digastrics (downward/backward vector)^{11,13,14}. Evaluation of the dual plot of opening movements and intermolar width change (Figure 11), indicates progressively larger amounts of flexure occur with opening movements. Individual signatures, however, show variations in the rate of intermolar width change. These minor changes might be due to differences in joint anatomy, varying amounts of force exerted by the muscles involved, mandibular dimensions, or differing bone densities. At a certain point in opening, the articular eminence acts as a mechanical constraint and the condyle drops and swings to continue opening until the condyle passes under the articular eminence. The temporomandibular ligament seems to keep the condyle in close proximity to the bone of the temporomandibular fossa during jaw opening until it passes under the articular eminence. At extreme opening, the sphenomandibular ligament may assist in keeping the condyle in close proximity to the temporal bone¹⁴. Closing motions are not necessarily the opposite those of opening and the resulting flexure occurring on closing is illustrated in the flexure signature examples (Figure 12). The opening sequence (left part of signature) is not identical to the closing sequence (right part of signature). In this example, with closing, the muscles of mastication may drive the condyle against the articular eminence, and because of its lateral

incline, may create a lateral force vector causing a rapid decrease in medial flexure. Elevator muscle forces and bone elastic rebound may also influence the return of the mandible to a undeformed state. There may be a potential clinical significance to the flexure signatures. Pathology might be detectable by examining individual signatures. Different patterns of jaw movement have been observed in patients with TMJ dysfunction³³. Patients with TMJ dysfunction may have different patterns of flexure than patients with healthy joints.

Contrary to previous studies^{14,16,20}, small amounts of mandibular flexure appeared to begin almost immediately when the mandible was depressed as illustrated (Figure 11) in the dual plot of the grand means of intermolar width change and opening movements. Intermolar width change appeared to begin with less than 10 mm of opening and continued in direct relation to opening movements. A maximum flexure value occurred with maximum opening which was sustained as long as the maximum opening position was held. This finding emphasizes the importance of minimizing mandibular opening during impressions. Dimensional change of the mandible in normal function is likely when the mandible is not even near border positions. Therefore, some type of stress breaking apparatus seems essential for the physiological use of any fixed prosthesis that crosses the mandibular symphysis.

The perimeter of the mandible had a weak positive correlation with intermolar width change for forced open

(assisted), left lateral, and protrusive border movements. The strongest positive correlation was to protrusive movements at a relatively weak correlation of $r=.308$ indicating that there was a slight tendency for a larger mandible to more likely have intermolar width change during protrusive movements. A larger mandible might provide a greater mechanical advantage to the muscles involved in protrusive movements. There was no significant correlation for wide open, or right lateral movements to mandibular size. The range for maximum opening was also weakly correlated to mandible size which seems obvious since a larger mandible should be able to open wider. Oddly, a relatively weak negative correlation ($r= -.309$, $p= .011$) exists for the range of protrusive movements. Thus, for the sample tested, the larger the mandible, the less distance a number of subjects were able to protrude.

Range of motion did not appear to have any significant correlation to the amount of intermolar width change occurring with border movements. Significant correlations, however, did exist between the maximum limits of motion in protrusive, left lateral, and right lateral directions. No correlations existed between the maximum range of opening and the other motions tested. Therefore, for the 58 subjects tested, the more the subjects could move their mandible in protrusion, the more lateral movement was possible but wider range of opening did not correlate with limits in other motions. Differences in range limits might have been due to differences in

ligamentous restraints. Lateral movements would have been a combination of rotation (on the side with a fixed condyle) and translation (on the movement side) and protrusive movements would have translation of both condyles. The fact that wide open maximum values did not correlate with lateral or protrusive movements may also have been influenced by the measuring technique. Overbite was not recorded as the sample subjects all had Class I molar relationships and were assumed to have minimal overbites. Individual variation, however, may have influenced the data. A more accurate representation of maximum opening would have included overbite values.

The sample size in this study was adequate but could have been more diverse. A greater range of subject groups with a balanced gender grouping, including younger children and older adults, may give a more comprehensive view of mandibular flexure. Also, a more accurate method of measuring border movements would have been helpful. With recent advances in technology, as provided by the Sirognathograph^r, an accurate, dynamic record of mandibular position in three planes of space may be possible.

^rSiemens Electric Ltd., Medical Systems, Mississauga, Ont. L5T 1P1.

Chapter 6

CONCLUSIONS

1. A significant amount of intermolar width change occurs in the transverse plane with assisted (forced) wide open, voluntary wide open, protrusive, left and right lateral border movements.
2. The mean amount of intermolar width change occurring with the mandibular border movements combined is not significantly less in adults (ages 21-28 years) than in adolescents (ages 13-15 years).
- 3
 - a) There was no significant correlation between the size (perimeter) of the mandible and the intermolar width changes occurring with voluntary wide open and right lateral border movements.
 - b) There was a weak correlation between the size (perimeter) of the mandible and left lateral and protrusive border movements.
4. There was no significant correlation between the range of motion of the mandible and the intermolar width changes occurring with mandibular border movements.

Suggestions for further study:

1. Longitudinal studies to:

- a. Determine if the amount of intermolar width change remains constant for a given individual over time.
- b. Determine if test subjects maintain similar flexure signatures over time.
- c. Include younger children, older adults, and both genders.

2. A study to determine if flexure signatures can be used as a diagnostic tool. For example, do a flexure signatures differ for gender, stature, mandibular dimensions, bone density, muscular strength, or in the presence of disease?

3. A study to determine where mandibular flexure is occurring during mandibular movements. How much flexure occurs in the symphysis, body, ramus, or condyles? In what plane does mandibular flexure occur? To help determine force levels of muscles during border movements, a mandibular model could be developed.

4. A study of intermolar width change with intraosseous implant patients to determine what happens to the mandible during mandibular movements since implant abutments have no periodontal compensations. Would some type of stress-breaker be advantageous?

5. A study of intermolar width change with temporomandibular dysfunctional patients. Do their flexure signatures differ from normal patients? Do their flexure signatures change over time?

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Appendix A

STUDY APPROVALS



University of Alberta
Edmonton

Faculty of Dentistry

72

Canada T6G 2N8

Dentistry/Pharmacy Centre

APPROVAL

FOR

PROPOSAL ON HUMAN RESEARCH

This is to certify that Dr. S. K. Davis, of the Division of Orthodontics, presented a proposal for clinical research on "Intermolar Width Changes Associated with Border Movements and their Relation to Age."

The Human Ethics Committee is satisfied that the ethical criteria for human research have been met.

HUMAN ETHICS COMMITTEE

DR. D. COLLINSON, CHAIR

DR. K. HINKELMAN, CHAIR,
DEPARTMENT OF RESTORATIVE DENTISTRY

DR. T. MCGAW, CHAIR
DIVISION OF PATHOLOGY

DR. C. BAKER, CHAIR
DEPARTMENT OF STOMATOLOGY

DR. D. DEDERICH, CHAIR, BIOMATERIALS

MARCH 23, 1989

CONSENT FORM

This study is being conducted to evaluate how the lower jaw bends when it is moving. The determination of these values is important to dentistry for accuracy in making bridges and various other appliances and will benefit future patients.

The tests will require your full cooperation for a period of approximately 30-45 minutes. No x-rays or medication will be used for these procedures. The testing will involve fixing a small steel ball to the outside of your first molars and also attaching a small magnet to the inside of your lower front teeth. A measuring device will fit over the steel balls and data will be collected as you move your jaw into different positions. The steel ball and magnet are easily removed after testing.

Your identity as a patient will be kept in confidence. No information identifying you by name will be revealed. Participants can withdraw from the program at any time. Information gained by this study will be used for research and educational purposes only.

We will be pleased to answer any questions regarding this study. Please feel free to contact Dr. Steve Davis(439-3065) for further information.

Thank you for your interest and cooperation in this study.

After having had the above study explained by Dr. Davis and having read the above letter, I hereby consent to participate in this study.

Patient name

Signature of patient/parent

(witness) & Date _____

Appendix B

MANDIBLE TRANSDUCER CALIBRATION FIGURES

Mandible Transducer Calibration Prototype

Displacement (inches)	Output (Volts)	Output (Volts)	Output (Volts)
0	0.00	0.00	1.00
0.005	0.04	0.04	0.95
0.010	0.09	0.09	0.90
0.015	0.15	0.14	0.85
0.020	0.20	0.19	0.79
0.025	0.24	0.24	0.75
0.030	0.29	0.29	0.71
0.035	0.34	0.34	0.65
0.040	0.39	0.39	0.61
0.045	0.43	0.44	0.56
0.050	0.48	0.49	0.51
0.055	0.53	0.53	0.46
0.060	0.58	0.58	0.42
0.065	0.63	0.63	0.37
0.070	0.69	0.69	0.31
0.075	0.73	0.74	0.27
0.080	0.79	0.79	0.22
0.085	0.84	0.84	0.18
0.090	0.89	0.89	0.11
0.095	0.94	0.94	0.06
0.100	0.99	1.00	0.00
	Run #1	Run #2	Run #3

NOTE: Run #1 and Run #2 - Output linearity checked in tension
 Run #3 - Output checked in compression
 Various preloads (within reason) do not affect calibration
 Good repeatability and rezero response

Excitation - 6.82 volts
 Gain Setting - 1.30
 0.1" = 1 volt (full scale)
 0.001" = 0.01 volts

Preload

10 Grams - 0.27 volts
 20 Grams - 0.54 volts
 30 Grams - 0.81 volts

Mandible Transducer #1 Calibration

Displacement (inches)	Output (Volts)	Output (Volts)	Output (Volts)
0	0.00	0.00	1.00
0.005	0.05	0.06	0.96
0.010	0.11	0.10	0.90
0.015	0.15	0.16	0.85
0.020	0.21	0.20	0.80
0.025	0.25	0.24	0.76
0.030	0.30	0.30	0.71
0.035	0.34	0.34	0.65
0.040	0.40	0.40	0.60
0.045	0.46	0.45	0.55
0.050	0.51	0.50	0.51
0.055	0.55	0.55	0.46
0.060	0.60	0.60	0.41
0.065	0.66	0.66	0.35
0.070	0.71	0.71	0.30
0.075	0.75	0.76	0.26
0.080	0.80	0.80	0.20
0.085	0.85	0.84	0.16
0.090	0.91	0.90	0.11
0.095	0.95	0.95	0.06
0.100	1.00	1.00	0.00
	Run #1	Run #2	Run #3

NOTE: Run #1 and Run #2 - Output linearity checked in tension
 Run #3 - Output checked in compression
 Reasonable preloads do not affect calibration curve
 Rezero and repeatability response good

Excitation - 7.00 volts
 Gain Setting - 1.79
 0.001" = 0.01 volts

Preload

10 Grams - 0.42 volts
 20 Grams - 0.84 volts
 30 Grams - 1.26 volts

Mandible Transducer #2 Calibration

Displacement (inches)	Output (Volts)	Output (Volts)	Output (Volts)
0	0.00	0.00	1.00
0.005	0.05	0.06	0.94
0.010	0.10	0.10	0.90
0.015	0.16	0.15	0.84
0.020	0.21	0.21	0.80
0.025	0.25	0.25	0.75
0.030	0.30	0.30	0.70
0.035	0.35	0.36	0.66
0.040	0.41	0.40	0.60
0.045	0.44	0.45	0.56
0.050	0.51	0.50	0.51
0.055	0.55	0.56	0.46
0.060	0.61	0.61	0.40
0.065	0.65	0.65	0.35
0.070	0.70	0.71	0.30
0.075	0.75	0.75	0.26
0.080	0.80	0.80	0.20
0.085	0.85	0.85	0.16
0.090	0.91	0.90	0.10
0.095	0.95	0.95	0.05
0.100	1.00	1.00	0.00
	Run #1	Run #2	Run #3

NOTE: Run #1 and Run #2 - Output linearity checked in tension
 Run #3 - Output checked in compression
 Reasonable preloads do not affect calibration curve
 Rezero and repeatability response good

Excitation - 7.00 volts

Gain Setting - 1.27

0.001" = 0.01 volts

Preload

10 Grams - 0.25 volts

20 Grams - 0.50 volts

30 Grams - 0.75 volts

Appendix C

MANDIBLE TRANSDUCER DIMENSIONS

Mandible Transducers

Use large radius for bending

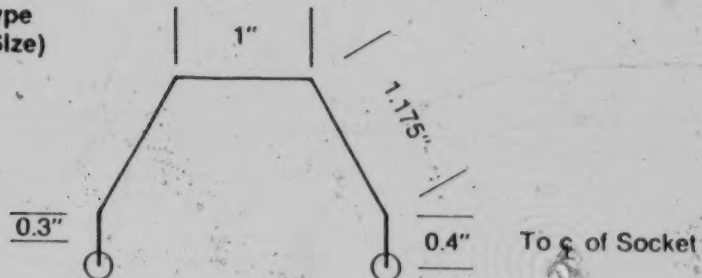
Material: S.S. Shimstock

0.5" Wide

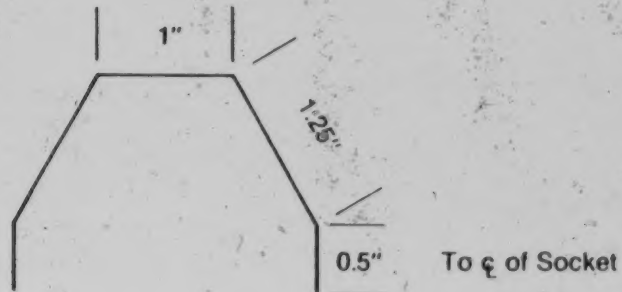
0.015" Thick

77

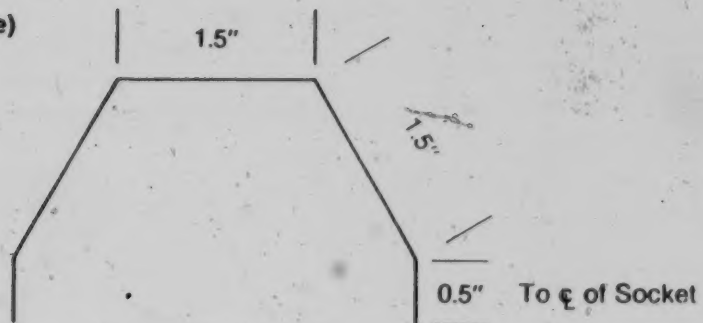
Prototype
(Small Size)



(Medium Size)
1



(Large Size)
2



Appendix D

TEST PROTOCOL

Appendix D

TEST PROTOCOL

A suitable subject was selected; in the age group 13-15 or 21-28 years, with an intact dental arch, an Angle class I molar relationship, apparent good periodontal health with negligible mandibular first molar mobility, and no apparent temporomandibular dysfunction.

The test procedure for determining intermolar width changes with mandibular border movements was as follows:

1. The computer and Kinesiograph were turned on and a formatted 5 1/4 inch disk was placed in drive B.
2. The Kinesiograph was set up to display the sagittal on the left. The right display was off.
3. The mandibular first permanent molars were isolated with cotton rolls, and dried with compressed air.
4. Glass ionomer cement was mixed and a small amount applied to the roughened bases of the steel balls. The steel balls were seated near the gingival margin of the buccal surfaces of the mandibular first permanent molars. A minimum of 5 minutes was allowed for the cement to set.
5. While the cement was setting, maximum opening, maximum protrusive, and maximum left and right lateral movements were hand measured with a millimeter ruler. Each border movement was repeated 3 times and measured to the nearest millimeter.

6. The mandibular soft tissue perimeter was measured with a flexible cloth tape measure. The distance from the middle of the tragus of one ear, following the soft tissue border of the mandible, to the middle of the tragus of the opposite ear was measured. The distance was measured 5 times and averaged to the nearest 0.5 cm.
7. After the glass ionomer cement was set, excess cement was removed and the mandible transducer was inserted. On one side of the mandibular arch, the teflon socket was gently applied over the cemented steel ball and then the transducer was slightly expanded to fit over the steel ball on the opposite first permanent molar.
8. The Kinesiograph magnet was applied to the lingual of the mandibular incisors with the provided cellulose adhesive making sure the north pole of the magnet was to the subject's left.
9. The Kinesiograph eye-glass framework was placed on the subject. Straps on the rear of the subject's head were secured to stabilize the framework.
10. The soft tissues were retracted with cheek retractors to prevent any soft tissue impingement on the mandible transducer or Kinesiograph framework. See Figure 10 for illustration of testing apparatus in place.
11. The strain gauge conditioner was balanced, while also observing the voltage, as viewed on the digital voltameter, did not exceed that representing 20 grams of preload.

12. The x/y coordinates on the Kinesiograph oscilloscope were centered to a zero reading and the magnetic sensor framework adjusted to have the oscilloscope trace coincide with the subject's maximum opening.
13. On the computer, the directory containing the data acquisition program GETDAT was selected.
14. The Kinesiograph calibration procedure was begun. Starting from a rest position, the subject opened maximally and the space bar was pressed. A high pitched beep was emitted by the computer indicating the maximum opening. The subject was then instructed to close into centric occlusion until light tooth contact. The space bar was again pressed and a low pitched beep was emitted by the computer. The hand measured maximum opening distance was then entered, completing the calibration sequence, and the monitor screen switched to the patient information menu.
15. Cursor keys were used to move from item to item within the menu. For subject name and number, the cursor was moved to the area desired and enter was pressed before keying in the information. Enter was pressed again and cursor moved to the next item. When selecting motions, enter was pressed and a X marked the motion selected. When all subject information was correct, the Esc key was pressed. There were then three possibilities: a) Press space bar. (That initiated data collection based on current information in the subject menu screen.), b)

Press the letter Q. (That terminated the program.), or
 c) Press any other key. (That returned the program to
 the subject information menu to make modifications.)

SUBJECT NO: _____		NAME: _____	
MOTION:		TRIALS:	MANUAL DATA:
☐	PR	☐	☐
☐	LL	☐	☐
☐	LR	☐	☐
☐	WO	☐	☐
☐	FO	☐	☐

Computer Program Menu

16. The subject was instructed to practice several of each border movement with the operator observing if there were any interferences. Excessive readings on the strip chart recorder indicated if the transducer was being bumped as the transducer was extremely sensitive.
17. The space bar was pressed, initiating data collection. A low pitched beep indicated data was being taken. A second identical beep, 3.2 seconds later, sounded when the data collection cycle was complete. If protrusion or lateral border movements were being taken, the computer waited for the manually observed distances to be entered.
18. Five trials to determine changes in intermolar width for each border movement were recorded. The sequence began with wide open border movements. On completion of the

wide open routine, the Kinesiograph framework was removed and the Kinesiograph was turned off. Intermolar width change with protrusive movements were then recorded, followed by left and right lateral border movements. The subject had 3.2 seconds between beeps to complete each border movement.

19. The subject was allowed to relax for a few minutes before measuring intermolar width change with forced opening. The spring loaded, forced opening device was then compressed and inserted. The ends of the extension rods rested on the incisal edges of the maxillary and mandibular anterior teeth. The subject was instructed to completely relax their jaw muscles and allow the spring to move their jaw. The space bar was pressed and, after 3.2 seconds of data collection, the forced opening device was compressed and removed. As with the other movements, the testing was repeated 5 times.
20. Upon completion of testing, the magnet was removed from the lingual of the mandibular incisor teeth and the steel balls were detached from the first permanent molars. Any residue of cement or cellulose adhesive was removed with a periodontal scaler.

All test information and data were stored on drive B. When the drive active light was on, data was being stored to drive B. Continuing onto the next trial or next test was not possible until the drive active light went out.

After testing a subject, if confirmation of data collection was desired, the file LOOKDAT was called up. The LOOKDAT file dumped any specified data file to the screen. To call up a file, the subject's number, abbreviated motion (WO, LL, LR, PR, CL, or FO), and trial number had to be specified. The data file name convention was B: ###@#.DAT, where B: = disk drive, ## = subject number, @@ = motion, and # = trial number (1 digit).

The order of data displayed was subject name, motion (2 letter code; i.e., wo = wide opening), trial number, calibration factor (mm/bit), manual data entered (maximum border movement distances for lateral and protrusive), and 999.9 was displayed if a motion did not require manual data. The routine then paused until any key was pressed and 755 pairs of points were displayed. The left set of digits were vertical readings and the right set of numbers were intermolar width changes. The vertical readings were only valid during testing of maximum opening border movements.

The information was stored in a binary or machine language to save time and space. A program called FCONVDAT converted the binary data file into an ASCII file for use with an editor or word processor.

The files of all the subjects were converted from a binary format into readings in millimeters. The converted files were subsequently taken to a statistician for analysis.

Appendix E

PILOT STUDY

Pilot Study: Strip Chart Recordings

subject: 28 years, male

28 Feb 89

	w/o	pro	l.lat	r.lat
mean	0.33mm	0.30mm	0.20mm	0.10mm
s.d.	0.05mm	0.05mm	0.03mm	.05mm

2 Mar 89

mean	0.33mm	0.33mm	0.18mm	0.10mm
s.d.	0.03mm	0.03mm	0.03mm	0.03mm

subject: 44 years, male

2 Mar 89

	w/o	pro	l.lat	r.lat
mean	0.18mm	0.34mm	0.08mm	0.05mm
s.d.	0.03mm	0.03mm	0.01mm	0.01mm

subject: 8 years, male

12 Mar 89

	w/o	pro	l.lat	r.lat	f/o
mean	0.15mm	0.20mm	0.02mm	0.05mm	1.35mm
s.d.	0.05mm	0.03mm	0.01mm	0.02mm	0.15mm

Appendix F**SAMPLE DISTRIBUTION TABLE**

Subject #	Sex (m/f)	Age (yr-mo)	Md Perl (cm)	Mx/O (mm)	LL (mm)	LR (mm)	Prot (mm)
2	m	25-7	32.0	48	15	15	12
3	m	24-11	30.5	49	7	8	7
4	m	24-0	37.0	70	7	9	8
6	f	22-4	32.5	51	11	12	7
8	f	23-3	33.5	38	8	8	5
9	m	25-2	33.5	59	11	10	7
10	m	23-2	31.5	50	11	11	9
11	m	26-2	33.5	50	11	13	10
12	m	22-1	32.5	43	8	8	12
13	m	23-3	31.5	51	13	12	7
14	m	21-8	34.5	59	8	8	6
15	m	26-1	33.0	48	12	9	9
16	f	25-7	30.5	58	11	11	8
17	f	23-3	30.5	57	15	11	9
18	m	14-11	31.5	52	7	7	9
19	m	25-6	34.0	58	11	14	7
20	m	25-8	32.0	48	10	10	9
21	m	23-10	33.0	50	13	13	10
23	f	23-6	30.0	42	10	9	8
24	m	23-4	36.0	48	10	8	4
25	m	21-6	36.5	51	12	12	8
26	m	26-8	36.5	56	9	10	9
27	m	23-3	30.5	50	15	12	8
28	m	14-2	30.0	48	12	11	10
29	m	25-10	34.0	60	12	11	9
30	m	28-10	37.0	50	11	10	6
31	m	28-0	32.5	50	11	12	11
32	m	23-4	33.5	53	10	10	9
33	f	14-7	30.5	60	15	13	10
34	m	24-4	32.5	47	12	11	7
35	m	23-4	35.0	50	11	8	8
36	f	14-1	32.0	49	12	10	7
37	m	25-4	34.0	50	13	13	9
38	f	14-0	29.5	45	12	12	11
39	m	25-7	34.0	52	11	11	9
40	f	14-10	29.5	43	13	13	7
41	f	14-0	30.5	45	13	13	8
42	f	14-11	31.0	47	10	10	12
43	f	14-6	33.0	57	12	12	11
44	m	14-7	31.5	60	13	13	8
45	m	13-0	34.0	54	9	10	7
46	m	13-11	34.0	60	13	13	9
47	m	13-6	32.0	52	14	12	10
48	m	24-9	35.0	46	10	10	7
49	m	13-7	32.0	60	10	10	8
50	f	14-6	28.5	51	13	13	9
51	m	13-11	32.5	55	10	10	11
52	f	14-1	30.5	52	11	9	9
53	f	12-6	27.0	41	10	10	8
54	f	14-7	28.5	45	11	11	7
55	m	15-7	33.0	49	11	12	8
56	m	15-4	31.5	60	11	13	11
57	m	15-3	33.5	54	13	16	11
58	m	14-9	29.0	49	13	16	11
59	f	14-1	29.0	43	10	9	9
60	m	13-6	32.0	44	11	9	10
61	m	13-4	31.0	60	14	13	11
62	m	13-9	31.0	55	8	7	9

Appendix G

INDIVIDUAL TRIAL MEANS

method error

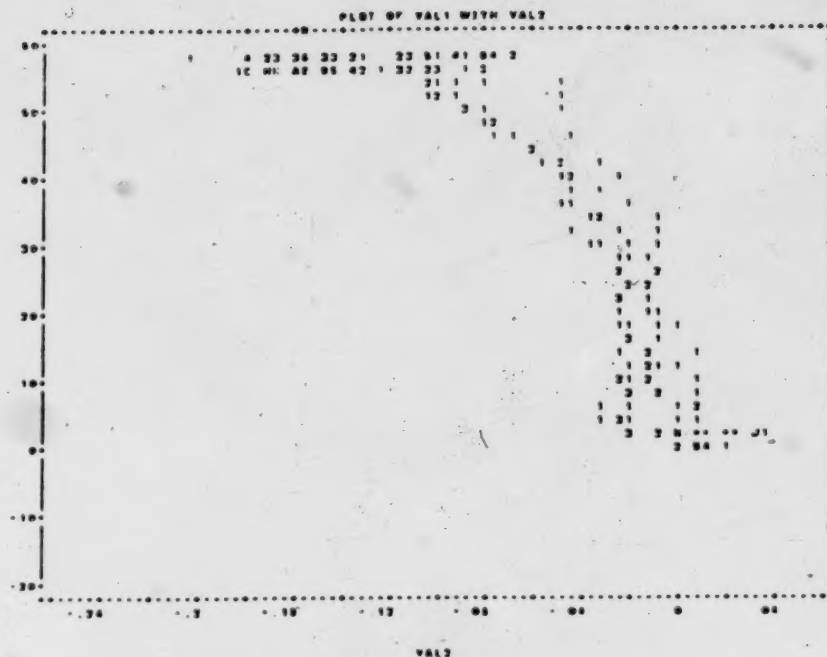
intermolar width change (mm)

	FO	LL	LR	PR	WO	
Adolescents Trials						
1	-0.195	-0.098	-0.083	-0.253	-0.267	Mean
2	-0.154	-0.094	-0.082	-0.263	-0.280	Mean
3	-0.173	-0.107	-0.088	-0.266	-0.299	Mean
4	-0.122	-0.093	-0.093	-0.262	-0.275	Mean
5	-0.135	-0.091	-0.106	-0.249	-0.302	Mean
S.D.	.029	.006	.009	.007	.015	
Young Adults Trials						
1	-0.149	-0.101	-0.089	-0.160	-0.286	Mean
2	-0.120	-0.104	-0.085	-0.179	-0.298	Mean
3	-0.131	-0.120	-0.097	-0.172	-0.275	Mean
4	-0.094	-0.127	-0.096	-0.163	-0.270	Mean
5	-0.132	-0.110	-0.091	-0.160	-0.298	Mean
S.D.	.020	.011	.005	.008	.013	

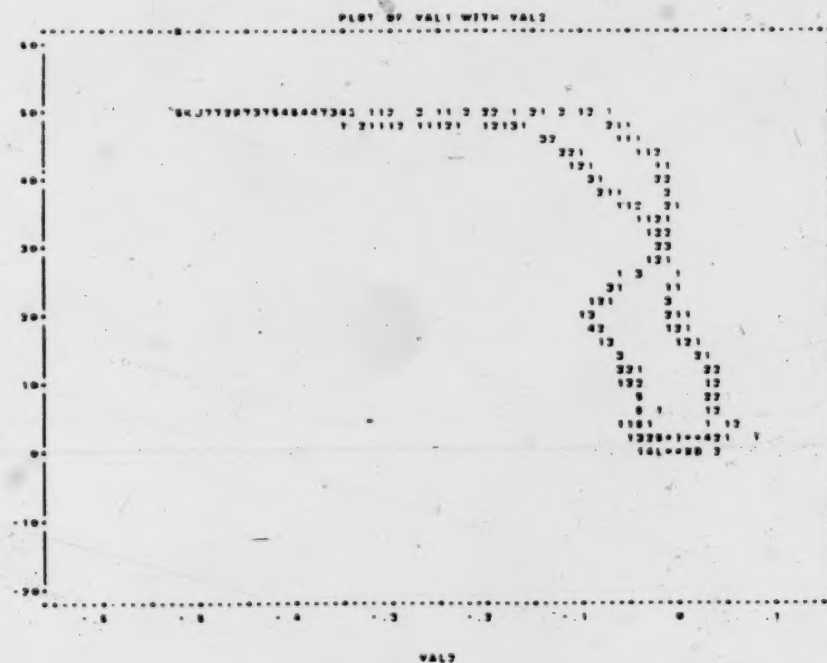
Appendix H

FLEXURE SIGNATURES

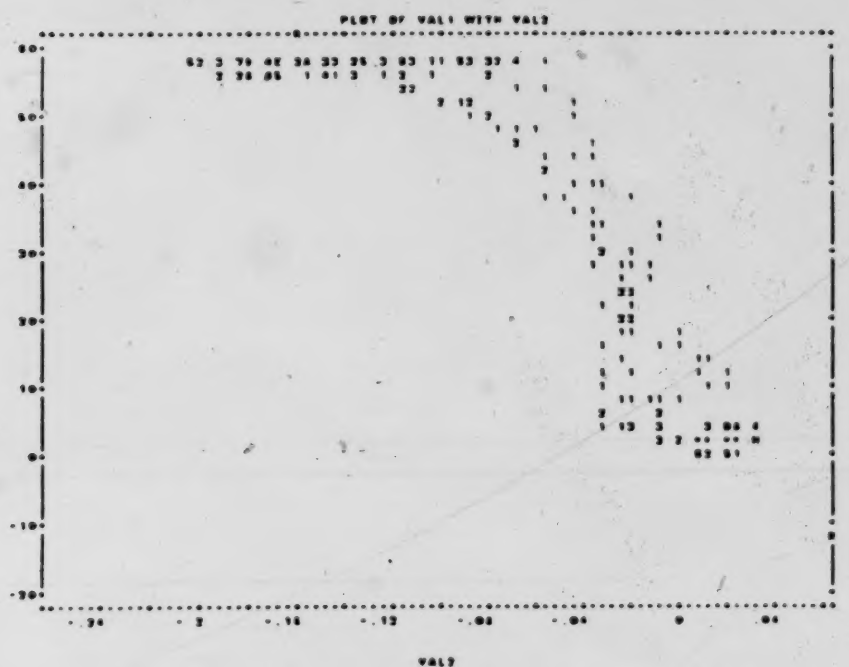
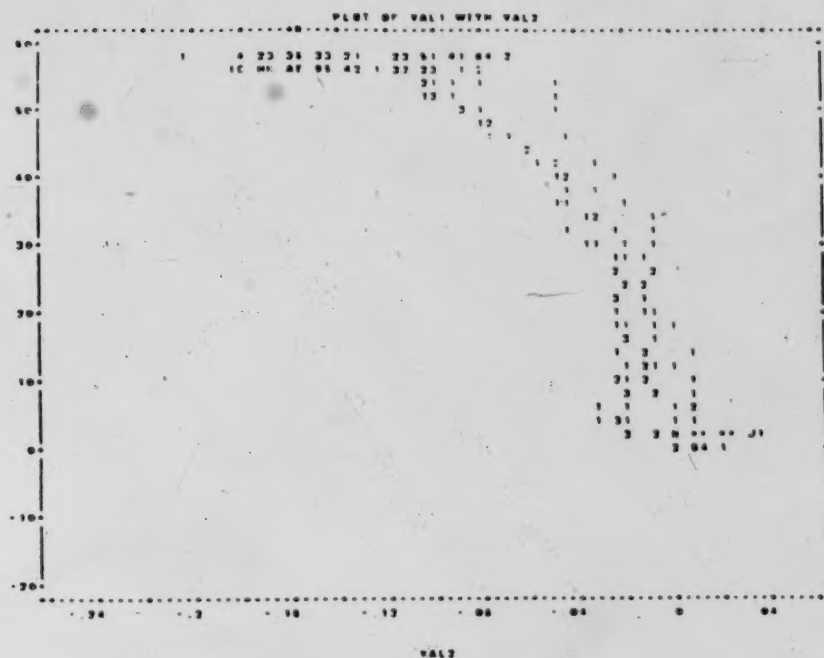
W3

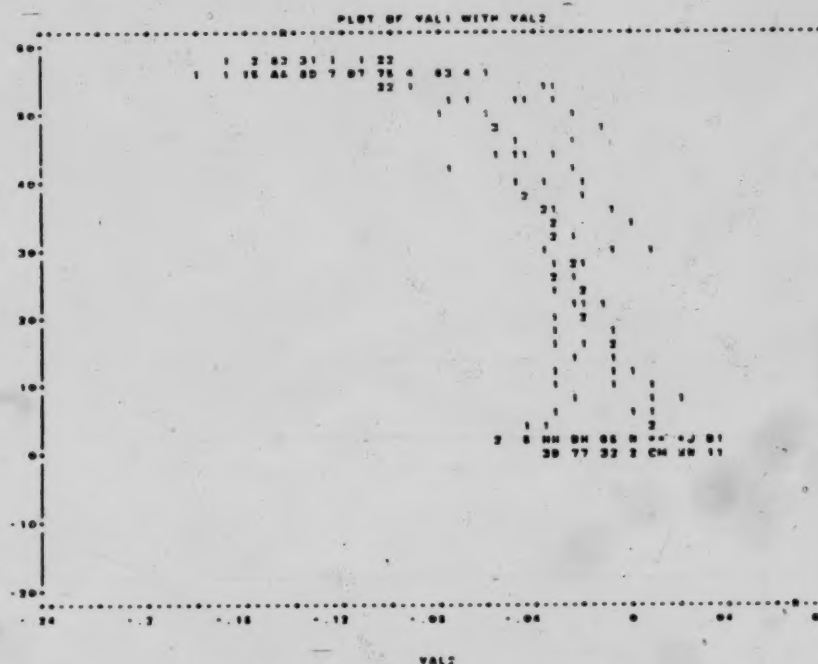
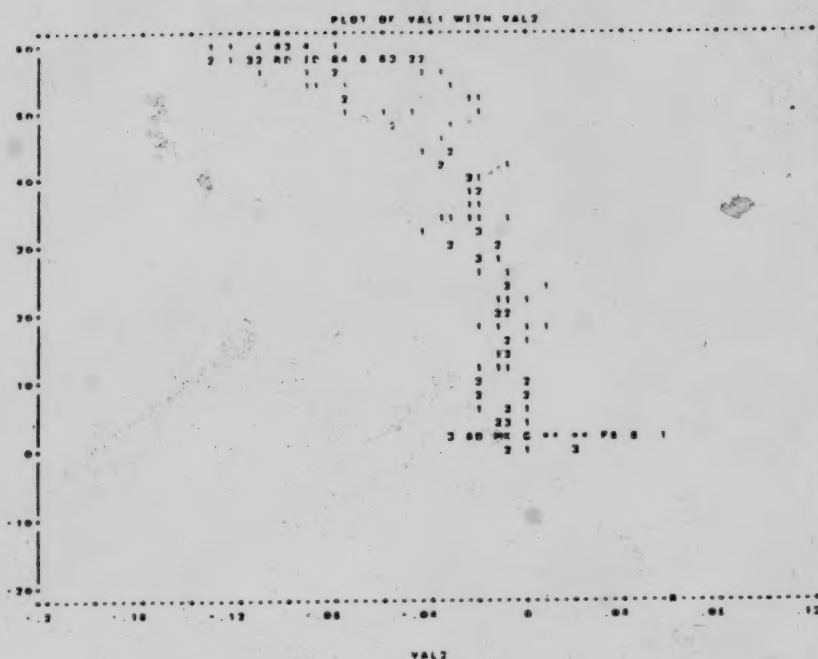


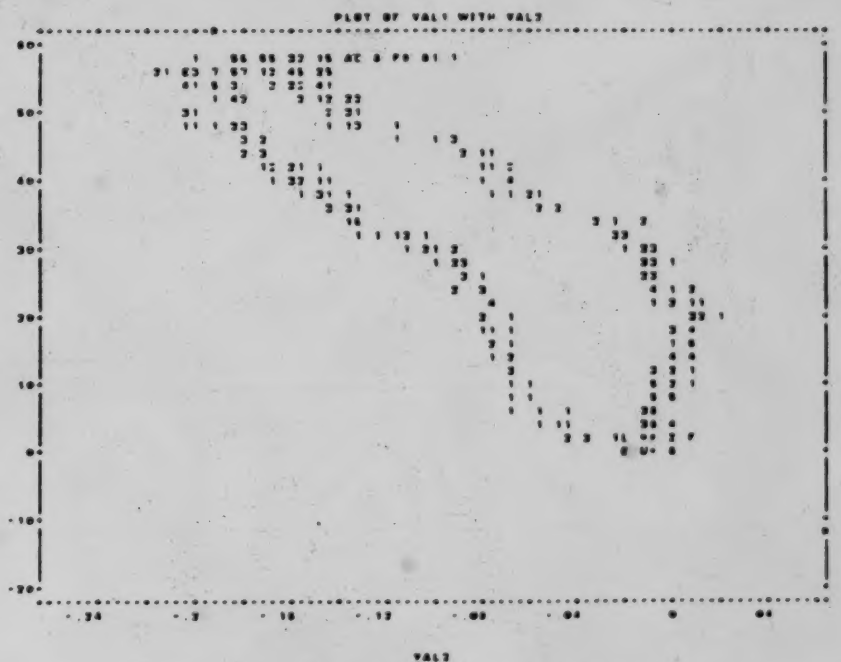
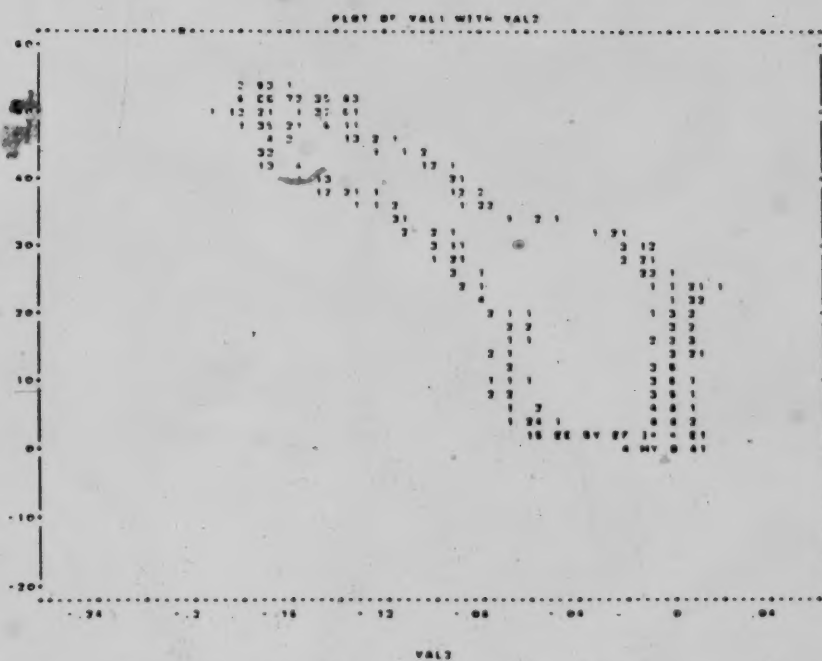
781 cases plotted. Regression statistics of VAL1 on VAL2:
 Correlation = .94857 R Squared = .89959 S.E. of Est = 7.51181 2-tailed Sig. = .0000
 Intercept S.E. = 7.642101 .291471 Slope S.E. = 339.738861 4.016901

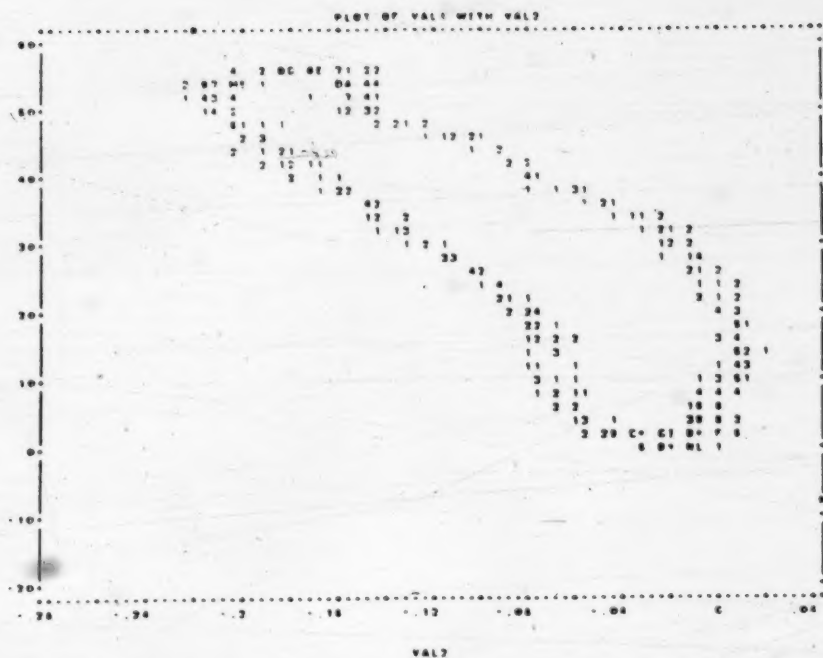


781 cases plotted. Regression statistics of VAL1 on VAL2:
 Correlation = .93833 R Squared = .79279 S.E. of Est = 11.42639 2-tailed Sig. = .0000
 Intercept S.E. = 8.744391 .430891 Slope S.E. = 101.780091 2.418101

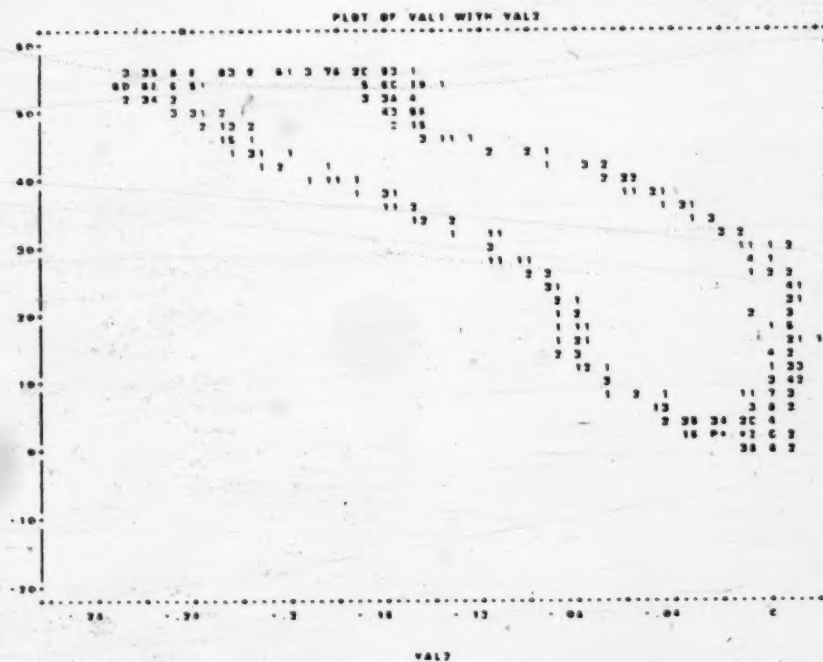








751 cases plotted. Regression statistics of VAL1 on VAL2:
 Correlation = .90286 R Squared = .81508 S.E. of Est = 9.84593 2-tailed Sig. = .0000
 Intercept(S.E.) = 3.818591 .491281 Slope(S.E.) = -.281.194531 4.840381



751 cases plotted. Regression statistics of VAL1 on VAL2:
 Correlation = .89256 R Squared = .80037 S.E. of Est = 10.39439 2-tailed Sig. = .0000
 Intercept(S.E.) = 6.809101 .630531 Slope(S.E.) = -.231.819951 4.845451

Appendix I**PEARSON CORRELATION COEFFICIENTS**

PEARSON CORRELATION COEFFICIENTS

	FO	LL	MX/LL	LR	MX/LR	PR
FO	1.0000 P=.	.3004 P=.011	.0546 P=.346	.4155 P=.001	.1284 P=.175	.4165 P=.001
LL	.3004 P=.011	1.0000 P=.	-.0439 P=.375	.5869 P=.000	.0284 P=.418	.4567 P=.000
MX/LL	.0546 P=.346	-.0439 P=.375	1.0000 P=.	.2294 P=.046	.7352 P=.000	.0115 P=.467
LR	.4155 P=.001	.5869 P=.000	.2294 P=.046	1.0000 P=.	.1558 P=.128	.4976 P=.000
MX/LR	.1284 P=.175	.0284 P=.418	.7352 P=.000	.1558 P=.128	1.0000 P=.	.0216 P=.438
PR	.4165 P=.001	.4567 P=.000	.0115 P=.467	.4976 P=.000	.0216 P=.438	1.0000 P=.
MX/PR	-.1494 P=.138	.0057 P=.483	.4031 P=.001	.162 P=.119	.323 P=.002	.087 P=.263
WO	.333 P=.005	.134 P=.155	.088 P=.260	.295 P=.015	-.033 P=.490	.545 P=.000
MX/O	.180 P=.277	.160 P=.117	.105 P=.226	.106 P=.222	.147 P=.144	-.066 P=.312
MDP	.271 P=.021	.267 P=.023	-.213 P=.061	.136 P=.164	-.130 P=.175	.308 P=.010

r values / probabilities p= to or < 0.05 for significance

FO = forced opening, LL = left lateral, RL = right lateral, PR= protrusive

WO = wide open, MDP = mandibular perimeter

MX/O, MX/PR, MX/LL, MX/LR = maximum range of motion

	MX/PR	WO	MX/O	MDP
FO	-.1494 (55) P=.138	.3331 (58) P=.005	.0802 (57) P=.277	.2712 (57) P=.021
LL	.0057 (55) P=.483	.1335 (60) P=.155	.1602 (57) P=.117	.2664 (57) P=.023
MX/LL	.4031 (55) P=.001	.0884 (55) P=.260	.1047 (54) P=.226	-.2128 (54) P=.061
LR	.1619 (55) P=.119	.2946 (55) P=.015	.1063 (54) P=.222	.1359 (54) P=.164
MX/LR	.3828 (55) P=.002	-.0033 (55) P=.490	.1474 (54) P=.144	-.1298 (54) P=.175
PR	.0872 (55) P=.263	.5484 (55) P=.000	-.0663 (57) P=.321	.3082 (57) P=.010
MX/PR	1.0000 (60) P=.	.1356 (55) P=.162	.0365 (54) P=.397	-.3094 (54) P=.011
WO	.1356 (55) P=.162	1.0000 (60) P=.	-.0747 (57) P=.290	.1260 (57) P=.175
MX/O	.0365 (54) P=.397	-.0747 (57) P=.290	1.0000 (58) P=.	.3778 (58) P=.002
MDP	-.3094 (54) P=.011	.1260 (57) P=.175	.3778 (58) P=.002	1.0000 (58) P=.

r values/ (cases) / 1-tailed significance

* * * is printed if a coefficient cannot be computed

Appendix J**SCHEFFE MULTIPLE COMPARISON TABLE**

MULTIPLE COMPARISONS: SCHEFFE ALGORITHM
 HYPOTHESIS TERM FOR COMPARISONS: AGE/TYPE
 ALPHA = 0.050000
 VARIABLE: INTERMOLAR WIDTH CHANGE (MM)
 * = SIGNIFICANT DIFFERENCES BETWEEN MEANS

AGE	TYPE					
ADOLES.	WO	FREQ	27			
		ESTMEAN	-0.29			
YOUNG ADULTS	WO	FREQ	30	REQ DIFF	0.11	
		ESTMEAN	-0.29	OBS DIFF	0.2716E-3	
				S.E.	0.03	
				D.F.	231.99	
				SCHEFFE	4.49	
ADOLES.	PR	FREQ	27	REQ DIFF	0.10	0.11
		ESTMEAN	-0.26	OBS DIFF	0.03	0.03
				S.E.	0.02	0.03
				D.F.	269.00	231.99
				SHEFFE	4.48	4.49
YOUNG ADULTS	PR	FREQ	30	REQ DIFF	0.11	0.09
		ESTMEAN	-0.17	OBS DIFF	0.12*	0.12*
				S.E.	0.03	0.02
				D.F.	231.99	269.00
				SCHEFFE	4.49	4.48
ADOLES.	PO	FREQ	27	REQ DIFF	0.10	0.11
		ESTMEAN	-0.16	OBS DIFF	0.13*	0.13*
				S.E.	0.02	0.03
				D.F.	269.00	321.99
				SCHEFFE	4.48	4.49
YOUNG ADULTS	PO	FREQ	29	REQ DIFF	0.11	0.09
		ESTMEAN	-0.13	OBS DIFF	0.16*	0.16*
				S.E.	0.03	0.02
				D.F.	234.60	269.00
				SCHEFFE	4.49	4.48

ESTMEAN					-0.29	-0.29
FREQUENCIES					27	30
TYPE					WO	WO
AGE					ADOLES.	YOUNG ADULTS

MULTIPLE COMPARISONS: SCHEFFE ALGORITHM
 HYPOTHESIS TERM FO COMPARISONS: AGE/TYPE
 ALPHA = 0.050000
 VARIABLE: INTERMOLAR WIDTH CHANGE (MM)
 * = SIGNIFICANT DIFFERENCES BETWEEN MEANS
 CONTINUED:

AGE	TYPE					
YOUNG ADULTS	LL	FREQ	30	REQ DIFF	0.11	0.09
		ESTMEAN	-0.11	OBS DIFF	0.17*	0.17*
				S.E.	0.03	0.02
				D.F.	231.99	269.00
				SCHEFFE	4.49	4.48
ADOLES.	LL	FREQ	27	REQ DIFF	0.10	0.11
		ESTMEAN	-0.10	OBS DIFF	0.19*	0.19*
				S.E.	0.02	0.03
				D.F.	269.00	231.99
				SCHEFFE	4.48	4.49
YOUNG ADULTS	LR	FREQ	28	REQ DIFF	0.11	0.09
		ESTMEAN	-0.09	OBS DIFF	0.19*	0.19*
				S.E.	0.03	0.02
				D.F.	237.35	269.00
				SCHEFFE	4.49	4.48
ADOLES.	LR	FREQ	25	REQ DIFF	0.10	0.11
		ESTMEAN	-0.09	OBS DIFF	0.19*	0.19*
				S.E.	0.02	0.03
				D.F.	269.00	238.63
				SCHEFFE	4.48	4.49

	ESTMEAN				-0.29	-0.29
	FREQUENCIES				27	30
	TYPE				WO	WO
	AGE				ADOLES.	YOUNG ADULTS

MULTIPLE COMPARISON: AGE/TYPE CONTINUED

AGE	TYPE	FREQ	ESTMEAN	REQ DIFF	OBS DIFF	S.E.	D.F.	SCHEFFE
YOUNG ADULTS	PR	30	-.17	0.11	0.09	0.03	231.99	4.49
ADOLES.	FO	27	-0.16	0.10	0.10*	0.02	269.00	4.48
YOUNG ADULTS	FO	29	-0.13	0.11	0.13*	0.03	234.60	4.49
ESTMEAN				-0.26	-0.17			
FREQUENCIES				27	30			
TYPE				PR	PR			
AGE				ADOLES.	YOUNG ADULTS			
YOUNG ADULTS	FO	29	-0.13	0.11	0.03	0.03	234.60	4.49
ESTMEAN				-0.16				
FREQUENCIES				27				
TYPE				FO				
AGE				ADOLES.				

MULTIPLE COMPARISONS: AGE/TYPE CONTINUED

AGE	TYPE					
YOUNG ADULTS	LL	FREQ	30	REQ DIFF	0.11	0.09
		ESTMEAN	-0.11	OBS DIFF	0.15*	0.05
				S.E.	0.03	0.02
				D.F.	231.99	269.00
				SCHEFFE	4.49	4.48
ADOLES.	LL	FREQ	27	REQ DIFF	0.10	0.11
		ESTMEAN	-0.11	OBS DIFF	0.16*	0.07
				S.E.	0.02	0.03
				D.F.	269.00	321.99
				SCHEFFE	4.48	4.49
YOUNG ADULTS	LR	FREQ	28	REQ DIFF	0.11	0.09
		ESTMEAN	-0.09	OBS DIFF	0.17*	0.08
				S.E.	0.03	0.02
				D.F.	237.35	269.00
				SCHEFFE	4.49	4.48
ADOLES.	LR	FREQ	25	REQ DIFF	0.10	0.11
		ESTMEAN	-0.09	OBS DIFF	0.17*	0.08
				S.E.	0.02	0.03
				D.F.	269.00	238.62
				SCHEFFE	4.48	4.49
ESTMEAN FREQUENCIES TYPE AGE				-0.26 27 PR ADOLES.	-0.17 30 PR YOUNG ADULTS	
YOUNG ADULTS	LL	FREQ	30	REQ DIFF	0.11	0.09
		ESTMEAN	-0.11	OBS DIFF	0.04	0.01
				S.E.	0.03	0.02
				D.F.	231.99	269.00
				SCHEFFE	4.49	4.48
ADOLES.	LL	FREQ	27	REQ DIFF	0.10	0.11
		ESTMEAN	-0.10	OBS DIFF	0.06	0.03
				S.E.	0.02	0.03
				D.F.	269.00	234.60
				SCHEFFE	4.48	4.49
ESTMEAN FREQUENCIES TYPE AGE				-0.16 27 FO ADOLES.	-0.13 29 FO YOUNG ADULTS	

MULTIPLE COMPARISONS: AGE/TYPE CONTINUED

AGE	TYPE					
YOUNG ADULTS	LR	FREQ	28	REQ DIFF	0.11	0.10
		ESTMEAN	-0.09	OBS DIFF	0.07	0.03
				S.E.	0.03	0.02
				D.F.	237.35	269.00
				SCHEFFE	4.49	4.48
ADOLES.	LR	FREQ	25	REQ DIFF	0.10	0.12
		ESTMEAN	-0.09	OBS DIFF	0.07	0.03
				S.E.	0.02	0.03
				D.F.	269.00	241.10
				SCHEFFE	4.48	4.48

	ESTMEAN				-0.16	-0.13
	FREQUENCIES				27	29
	TYPE				FO	FO
	AGE				ADOLES.	YOUNG ADULTS

ADOLES.	LL	FREQ	27	REQ DIFF	0.11	
		ESTMEAN	-0.10	OBS DIFF	0.01	
				S.E.	0.03	
				D.F.	231.99	
				SCHEFFE	4.49	
YOUNG ADULTS	LR	FREQ	28	REQ DIFF	0.09	0.11
		ESTMEAN	-0.09	OBS DIFF	0.02	0.5714E
				S.E.	0.02	0.03
				D.F.	269.00	237.35
				SCHEFFE	4.48	4.49
ADOLES.	LR	FREQ	-0.09	REQ DIFF	0.11	0.10
		ESTMEAN	25	OBS DIFF	0.02	0.6162E
				S.E.	0.03	0.02
				D.F.	238.62	269.00
				SCHEFFE	4.49	4.48

	ESTMEAN				-0.11	-0.10
	FREQUENCIES				30	27
	TYPE				LL	LL
	AGE				YOUNG ADULTS	ADOLES.

MULTIPLE COMPARISONS: AGE/TYPE CONTINUED

AGE	TYPE				
YOUNG	LR	FREQ	28		
ADULTS		ESTMEAN	0.09		
ADOLES.	LR	FREQ	25	REQ DIFF	0.12
		ESTMEAN	-0.09	OBS DIFF	0.4481E-3
				S.E.	0.03
				D.F.	243.69
				SCHEFFE	4.48

ESTMEAN	-0.09
FREQUENCIES	28
TYPE	LR
AGE	YOUNG
	ADULTS